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DEPARTMENT OF PUBLIC WORKS AND BUILDINGS
Division of Highways
Bureau of Research and Development

INTERIM REPORT
ON
TFE EXPANSION BEARINGS FOR HIGHWAY BRIDGES

by

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Conducted by the
Illinois Division of Highways
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TFE EXPANSION BEARINGS FOR HIGHWAY BRIDGES

ABSTRACT

This report covers the experimental work done to investigate the potential use of TFE as a sliding surface for highway bridge bearings. The research includes a comparison of TFE bearings with the bronze bearings which are currently used on prestressed concrete bridges. Samples supplied by various manufacturers were tested to determine the characteristics of TFE surfaces containing different amounts of glass fiber filler and to evaluate the effect of different types of backing material on the performance of the bearings.

Both laboratory and comparative field tests were conducted to measure the relative behavior of the various bearing configurations. This report includes a description of the test procedures, an analysis of the data obtained, and a discussion of observations made during the testing program.

The results of the research indicate that TFE bearings are suitable for use in highway bridges. From the conclusions derived from the study, design specifications are presented and recommendations are made for achieving the optimum TFE bearing configuration.

ACKNOWLEDGMENTS

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Acknowledgment is made of the assistance of others in the collection and reduction of field and laboratory data. Mr. Wesley J. Crake, Engineering Technician, Products Evaluation Unit, performed the field measurements and reduced and tabulated the field and laboratory data. Mr. Edward J. Kubiak, Engineer of Instrumentation Development, Instrumentation Development Unit, designed, constructed, and operated the special testing machine which was used in the laboratory tests.

SUMMARY

The use of TFE (tetrafluoroethylene) as a sliding surface for expansion bearings is of interest to highway engineers who are searching for ways to improve existing bearing designs. The properties of TFE which make it potentially suitable for use as a bridge bearing include an antistick surface, a low coefficient of friction, and chemical inertness. This project was conducted to evaluate the performance of TFE surfaces in conjunction with various backing materials and to obtain information for use in future bearing design.

Many combinations of TFE surfaces and backing materials are commercially available, and the selection of the optimum bearing for a specific application is complicated by this variety of products. The bearings tested during the research consisted of samples obtained from several manufacturers. The test results illustrate the differences in the performance of specimens obtained from the several manufacturers as well as differences in the performance of specimens obtained from the same manufacturer. This variation complicated the analysis of the experimental results, especially for the TFE specimens containing a mineral filler.

Parameters investigated during this research include the coefficient of friction of TFE surfaces containing varying amounts of glass fiber filler, hardness and shape factor of elastomeric backing materials, fatigue life of the bearing assemblies, and effects of contamination. Although the limited number of samples tested for investigating some parameters reduced the degree of confidence for the recorded data, certain trends relating to the performance of the specimens could be established. By studying the trends of the parameters both individually and collectively, the combination of materials resulting in the most effective bearing was determined.

Tentative conclusions based on the test results are as follows:

1. Pure unfilled TFE material appears to be more suitable for highway bridge bearings than TFE material reinforced with glass fiber filler. The use of 15 to 25 percent glass filler resulted in a 35 to 50 percent increase in the values for the coefficient of friction under applied normal loads between 200 and 800 psi.
2. Rubber compound used for backing material should have a minimum hardness of 70. Excessive distortion of the softer rubber backing occurred under the applied test loads.
3. Fabric backing materials are suitable only when used in conjunction with unfilled TFE. Several fabric-backed specimens with filled TFE surfaces failed by delamination of the fabric pad.
4. The performance of fabric backing materials in conjunction with filled TFE surfaces could be substantially improved by increasing the thickness of the fabric to a minimum of 1 1/2 inches.
5. A steel reinforcing laminate should be bonded between the TFE and backing material for bearings backed by rubber. A steel laminate is also somewhat beneficial when used in conjunction with the fabric backing.
6. The loosely woven surface of pure TFE fibers absorbed contaminating particles more effectively than the solid TFE surfaces.
7. The unfilled TFE-surfaced bearings consistently performed better than the currently used bronze bearings.

Based on the above tentative conclusions, TFE expansion bearings of a suitable design can be used for highway bridges. In particular the TFE bearings should be used in lieu of the graphite-impregnated self-lubricating bronze bearings currently used on prestressed concrete bridges. Other TFE bearing configurations may provide adequate performance; however, for optimum durability and economy designs based on the above guidelines are recommended.

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TFE EXPANSION BEARINGS FOR HIGHWAY BRIDGES

INTRODUCTION

The use of TFE (tetrafluoroethylene) as a potential sliding surface for bridge expansion bearings is of interest to highway engineers who are concerned with past problems relating to the durability of existing types of bearings. In certain cases the lack of durability or loss of performance under prolonged service has resulted in serious damage to the main structural components of a bridge. Consequently, extensive remedial work is required in order to restore the structure to its original condition. This study was undertaken to investigate the suitability of various combinations of TFE bearing designs for application to highway bridges and to compare the performance of TFE expansion bearings with certain types of bearings in current use.

Expansion bearings generally perform the basic functions of transferring vertical loads from the main structural members to the supporting substructure units and of allowing free longitudinal translation and rotation at the supports of the superstructure. Forces eliminated or reduced by permitting free movement of the structure commonly are those that result from longitudinal thermal expansion, creep due to prestressing, concrete shrinkage, shifting of the abutments, and beam shortening and end rotation due to live load deflections.

In addition, an expansion bearing compensates for the nonparallel surfaces of the bearing seat and the beam. These nonparallel surfaces often occur as a result of the roadway profile grade, camber in the prestressed beam, or vertical misalignment of the beam and bearing seat during construction of the structure. By being free to rotate, the expansion bearing is self-adjusting to the variable conditions encountered with nonparallel surfaces.

Most maintenance problems are encountered when the free movement of the bearings becomes restricted due to excess corrosion and electrolytic action. Bearings that become frozen can result in deflection of pier caps, disintegration of masonry bearing seats, and severe cracking and spalling at the ends of concrete beams. Considerable maintenance costs are often required to correct these situations as they arise.

Until the early 1960's, fifty years had passed with little progress made in the development of new materials and design concepts for highway bridge bearings.

Recent developments in the technology of TFE (tetrafluoroethylene) or fluorocarbon resins have made it possible to consider new concepts in the design of structural expansion bearings. Technical information furnished by various suppliers and distributors of TFE materials indicates that the product has certain physical and chemical properties which render it potentially useful in conjunction with highway bridge construction. Some of the desirable properties of TFE include an antistick surface, a low coefficient of friction, and a chemical inertness. These characteristics are ideal for expansion bridge bearings that are normally exposed to a corrosive environment for an extended period of time.

Publications from the manufacturers also indicated less desirable properties possessed by the material, including low wearability and a low resistance to compressive creep, that reduced the suitability of the pure material for certain applications. Most of the information received, however, reported that the deficiencies in the mechanical properties of the pure TFE can be compensated for by compounding certain inorganic fillers with the resins. The most widely used filler is glass fiber, which has the least chemical effect and greatly adds to the resin's wear and creep resistance.

Various ideas have been advanced by fabricators regarding the optimum design of highway bridge bearings utilizing a TFE sliding surface. The tentative designs which, at the beginning of the study, appeared to be the most practical and economical employed backings of elastomeric or rubber-impregnated cloth duck with a sliding interface of the glass-filled TFE material.

On the basis of information received from various manufacturers, TFE-faced elastomeric expansion bearings have several advantages when compared with other types of bearings. They are significantly less expensive, have fewer maintenance problems, and require less construction depth than the steel rocker or roller type bearings. In addition, they are not limited in translation as are the shear type elastomeric expansion bearings.

In order to study the behavior of TFE material when used as a bridge bearing, a testing machine was designed and assembled which could simulate certain loading conditions that are normally encountered by bridge bearings under field conditions. Laboratory tests were initiated on several types of filled and unfilled TFE bearings with various types of backing materials. Also, selected types of TFE bearings were installed on a prestressed beam bridge to study the behavior of the bearings under field environmental conditions. A test structure near Mt. Vernon was selected for a field evaluation of the TFE bearings.

The project is designed to determine the practicability and relative efficiency of various combinations of TFE expansion bearing designs and to obtain information for use in future bearing designs. This report on the project includes a description of the laboratory test equipment and procedure, a presentation of the test data compiled, a review of the results of the field research, and the conclusions derived from the study.

RESEARCH OBJECTIVES

The specific aims of this research are to evaluate the performance of TFE-faced expansion bearings for use as highway bridge bearings and to develop the most suitable design for application as abutment bearings for precast prestressed concrete I-beam bridges. The factors considered for developing an appropriate bearing design are economy, maintenance free durability, and performance under various conditions of loading. The study consists of a comparative evaluation on the performance of several types and combinations of TFE, steel, and elastomer materials and includes an investigation of the comparative behavior of TFE-faced bearings in relation to the presently used self-lubricating graphite bronze bearings.

The investigation is divided into two major phases of evaluation: (1) a direct field application of a series of different prototype bearing assemblies and (2) laboratory testing of diverse specimens subjected to various combinations of loading conditions.

FIELD TEST DESCRIPTION

A test structure was selected for an initial trial installation of five TFE bearing types to evaluate their performance in relationship to the field performance of the bronze bearings. The bridge selected is identified as FAI Route 57, Section 41-4HB-1, Jefferson County, which carries the traffic of Township Road 101 over Interstate 57 (Figure 1). The structure is an Illinois standard design for a four-span continuous prestressed I-beam bridge fixed against longitudinal movement at the center pier with expansion provided at the intermediate piers and abutments (Figure 2).

The girders in the bridge are Illinois standard 48-inch precast prestressed I-beam units of 42-foot lengths in the end spans and 70-foot 2-inch lengths in the center spans. Five girders spaced at 6-foot 6-inch centers are provided for

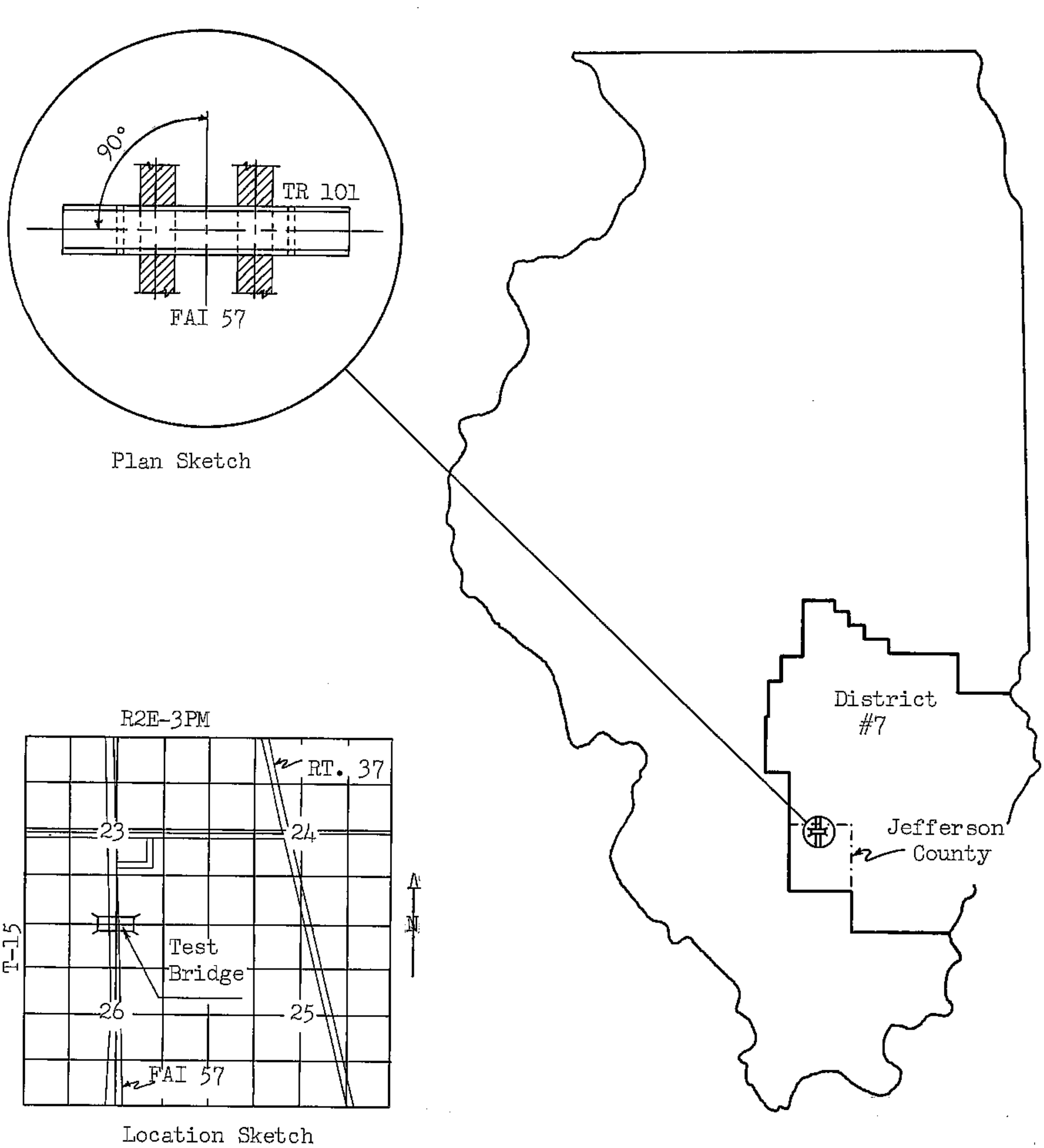

Figure 1. Location sketch of structure for field test of TFE bearings.

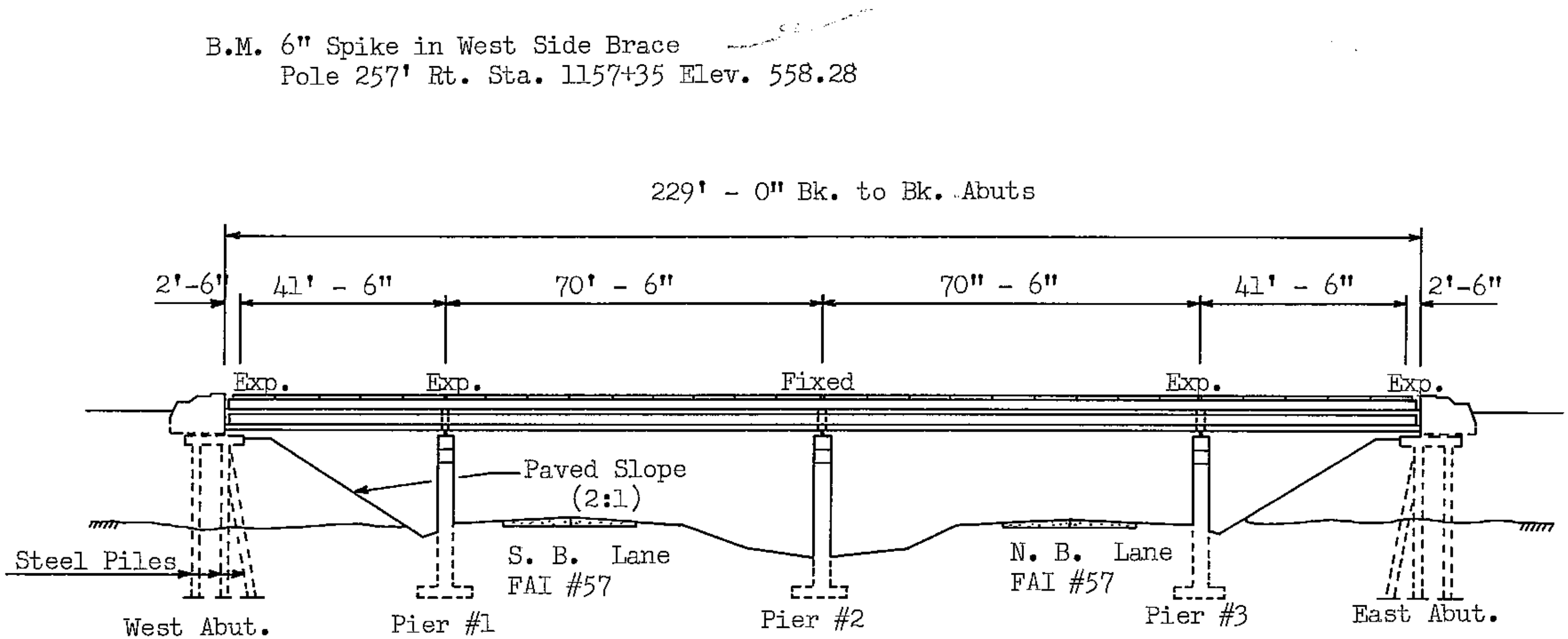

Figure 2. Elevation of Test Structure

(0° Skew)

Figure 2. Elevation of test structure.
(0^{o} skew)

supporting a roadway 24 feet in width (Figure 3).

In July 1967, five TFE sliding bearings of different configurations (labeled F4, F7, N1, N2, and N3 in Appendix A) were incorporated as the experimental feature at the west abutment. Five self-lubricating bronze graphite bearings designed according to current standards were installed at the east abutment to serve as the control for making a comparative evaluation of the performance of the two types of sliding bearings. Laminated elastomeric bearing pads, which are conventionally used for this type of construction, are provided at the intermediate piers to permit longitudinal movement of the superstructure. Details of the bearings and construction features are shown in Figures 4 and 5.

The experimental TFE bearings originally incorporated in the test structure were left in place until the laboratory test results indicated that these bearings did not withstand the applied loads as well as other TFE bearings. After remaining in service for approximately three years and four months, four of the five TFE bearings were removed and replaced with bearings N5, N13, M1 (page 52), and N5.

The fifth test bearing, which was type F4, was left in place because the field test of the fabric-backed specimens showed no signs of delamination even though the laboratory tests resulted in severe delamination of the fabric backing material. For this reason, it was decided to extend the field testing of the F4 bearing. The opposing sliding surface for all newly installed bearings is a 10 gage polished stainless steel sheet.

The five bronze self-lubricating bearings were left in place for continued study and comparison with the TFE bearings.

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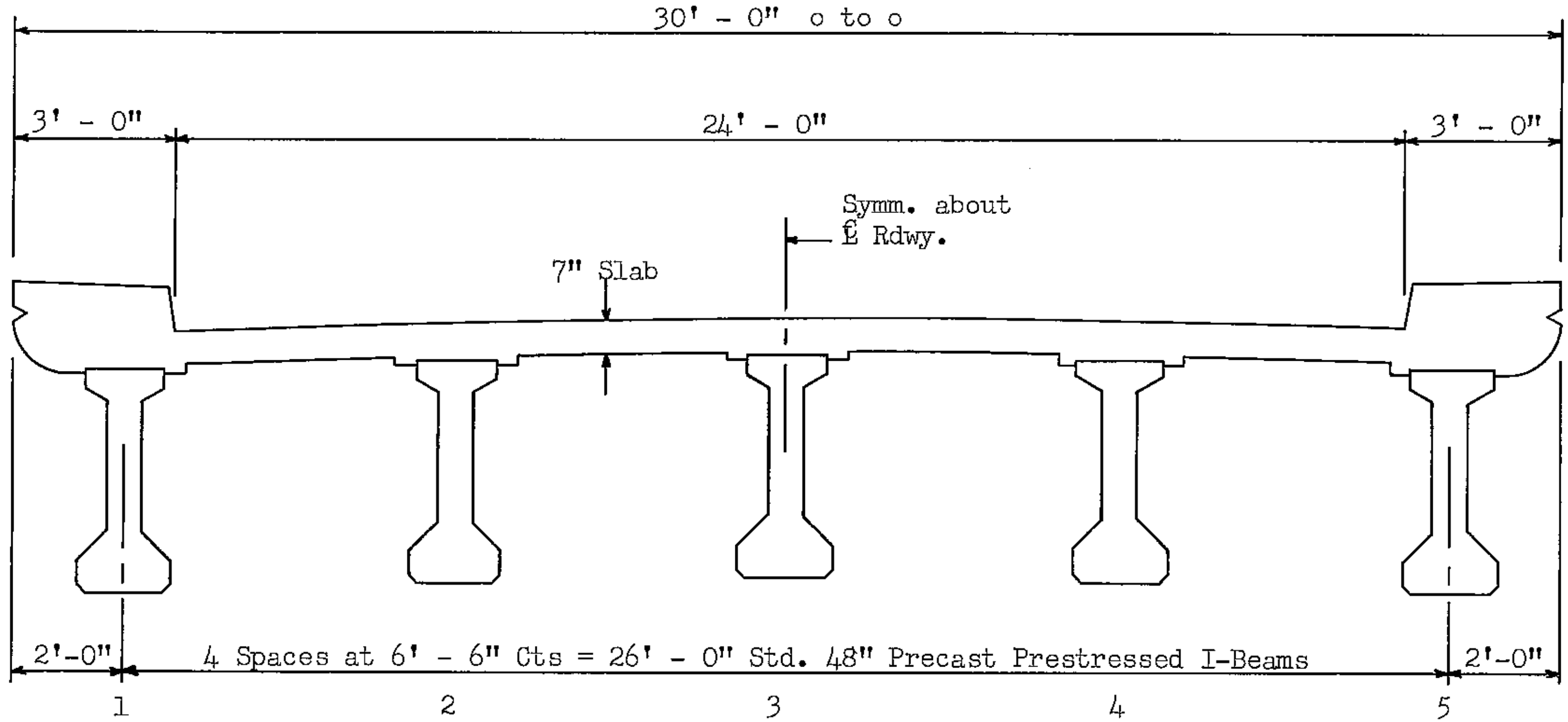

Figure 3. Cross Section of Test Structure

Figure 3. Cross section of test structure.

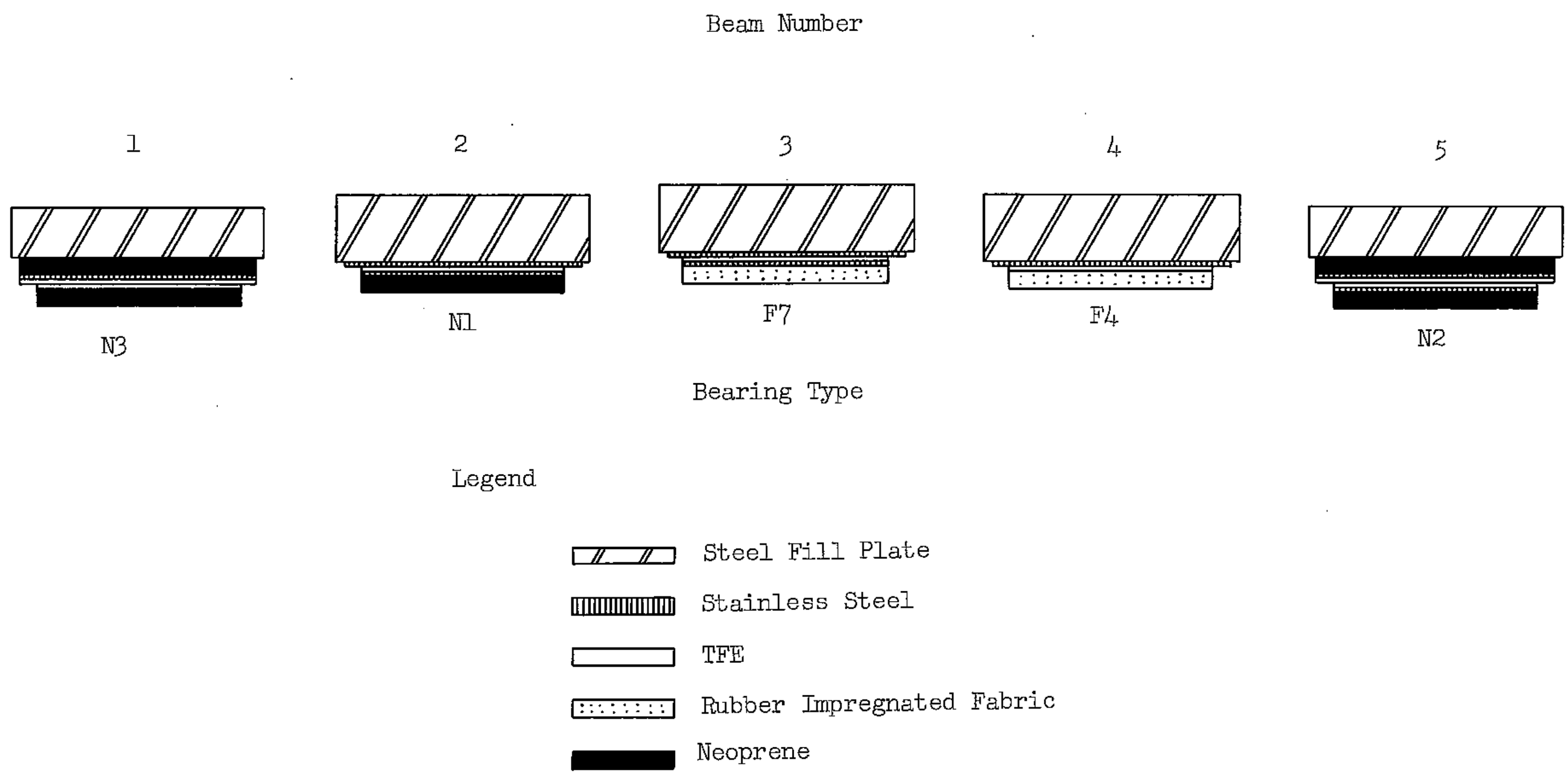

Figure 4. Cross Section of Bearings – West Abutment Looking West

Figure 4. Cross section of bearings - west abutment looking west.

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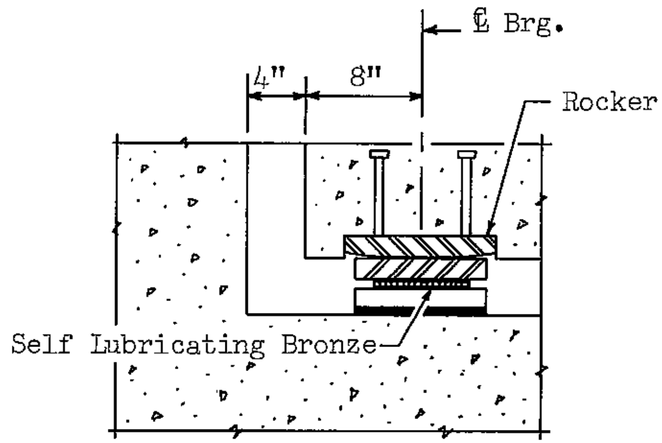
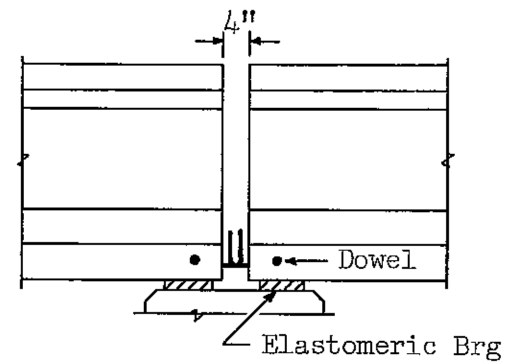
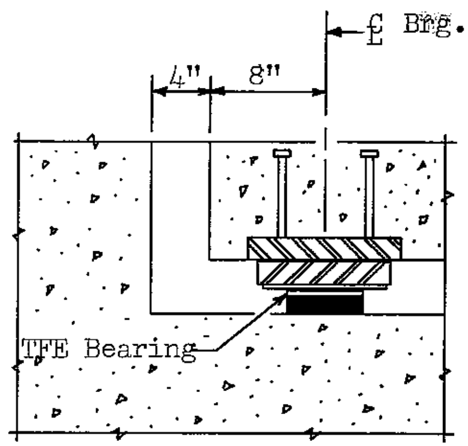


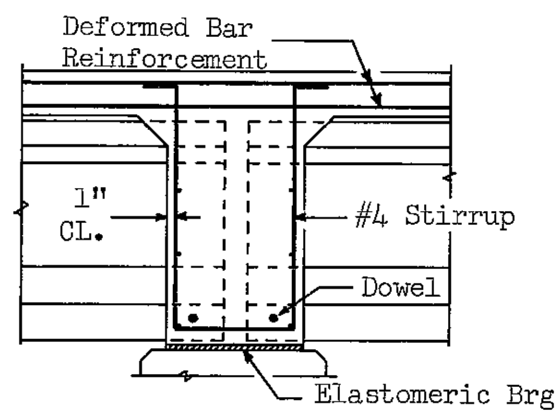
Section at East Abutment



Section at Expansion Pier
Prior to Casting Slab



Section at West Abutment
(See Figure #4)



Section at Expansion Pier
After Casting Slab

Figure 5. Sections at Expansion Supports.

Figure 5. Sections at expansion supports.

FIELD TEST RESULTS

Throughout the duration of the initial field tests, periodic inspections were made to determine the physical condition and performance of the bearings. The condition of all TFE field test bearings after remaining in service for three years and four months can be described as good.

The TFE surfaces of the neoprene-backed pads with a stainless steel layer bonded between the neoprene and TFE (N1 and N2) showed little signs of sliding or wear. The measured movements of the structure at these bearings did not appear to be of sufficient magnitude to cause significant sliding of the TFE interfaces. Apparently, most of the movement was accommodated by the deformation of the neoprene backing pad. Upon removal, the only evidence of permanent deformation was a slight bulging at the sides of the neoprene pads due to creep of the neoprene material under sustained loading. This deformation did not appear to affect the performance of the bearing.

The one test bearing consisting of a TFE layer bonded directly to the neoprene backing pad (N3) distorted upon removal of the load as did the laboratory specimens of the same configuration. When removed from the structure, the specimen deformed with a slight curvature which was convex when viewed from the top surface (Figure 6). This distortion did not occur, however, until the load was removed and did not appear to affect the performance of the bearing while installed in the structure.

Present on the TFE surfaces of all neoprene-backed pads both with and without steel interlayers were depressed and raised areas indicative of localized deformation of the TFE surface layer (Figure 7). Close examination of one specimen indicated that an uneven layer of adhesive was used to bond the TFE layer to the backing material. Although the uneven surface theoretically would increase

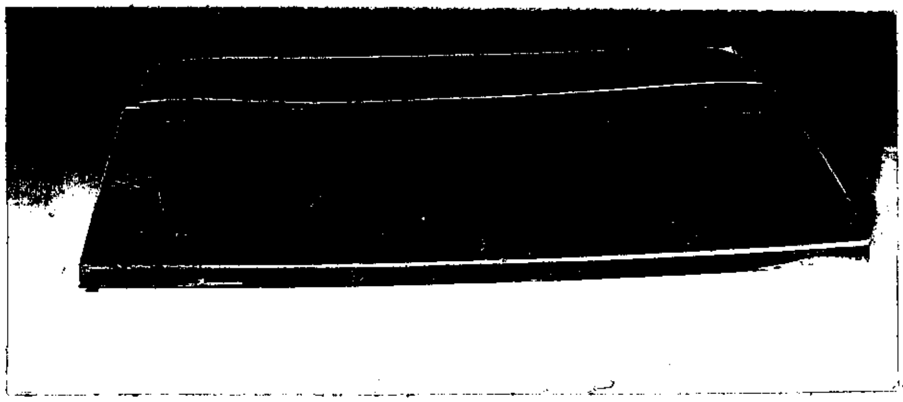


Figure 6. Distortion of field specimen N3.

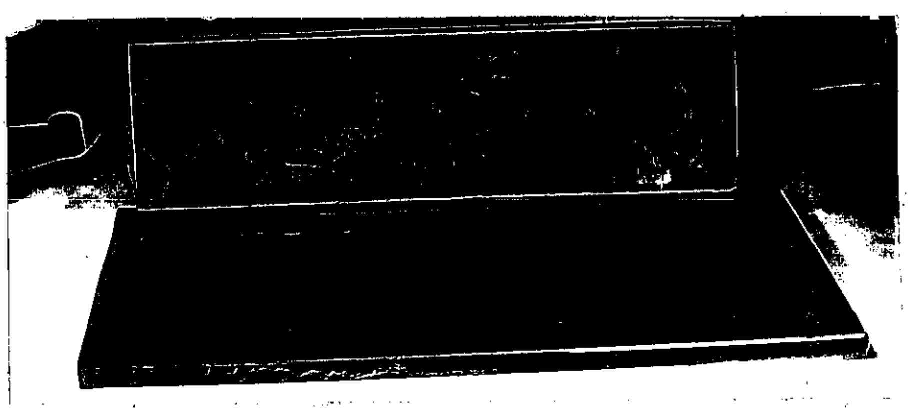


Figure 7. Raised and depressed areas of field specimen N1.

frictional forces somewhat, this unevenness did not appear to impair the overall performance of the bearings in allowing longitudinal movement.

As noted previously, the fabric-backed bearing pads showed no signs of delamination after more than three years of field testing. The only visible signs of wear on these pads were due to contamination of the surface layer by small particles of grit which were embedded in the TFE layer (Figure 8). The source of the contamination is unknown at this time, although it is believed to have occurred during the original installation of the bearings.

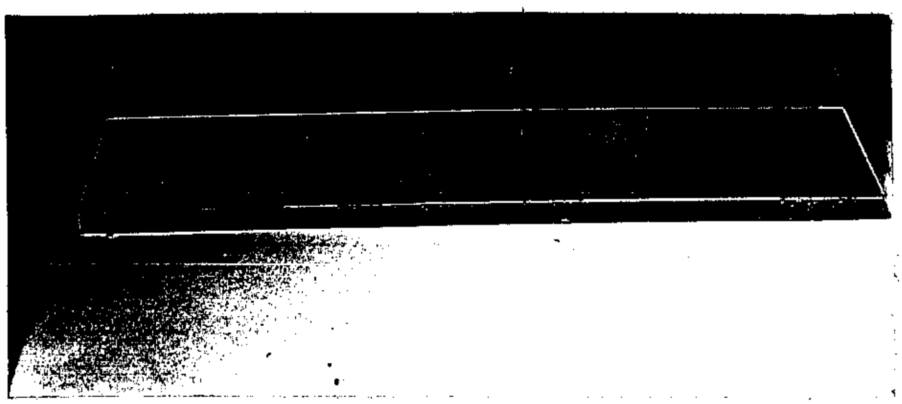


Figure 8. Contamination of field specimen F7.

The effects of the dirt particles upon the performance of the bearing were minor and did not appear to restrict longitudinal movement of the structure.

The most significant result gained from the field tests was the direct performance comparison of the TFE bearings with the bronze bearings. The results of the field tests are presented graphically in Figures 9 through 11 which chart the longitudinal movements of the bearings at different hours of the day and night and at different seasons of the year. As indicated on the daily variation graphs, almost twice as much movement took place at the TFE bearings compared with the bronze bearings. From these results it appears that the TFE bearings are more effective in allowing longitudinal expansion and contraction of the superstructure than are the bronze self-lubricated bearings.

LABORATORY TEST DESCRIPTION

A program of laboratory testing was undertaken as a means of accelerating horizontal translational movements of typical bearing assemblies under vertical loads simulating normal and extreme field conditions. This program of accelerated testing was implemented so that results could be obtained quickly for an early evaluation of the possible application of TFE sliding bearings for highway bridges.

Test Equipment

Specially constructed test apparatus was fabricated for the project. The apparatus, which utilizes an existing 250,000 pound capacity hydraulic compression machine, consists of three basic components: (1) the hydraulic press equipped with a gage for establishing the applied vertical loads, (2) a mechanical drive for inducing translational motion, and (3) a frame for supporting the hydraulic compression tester and the drive mechanism.

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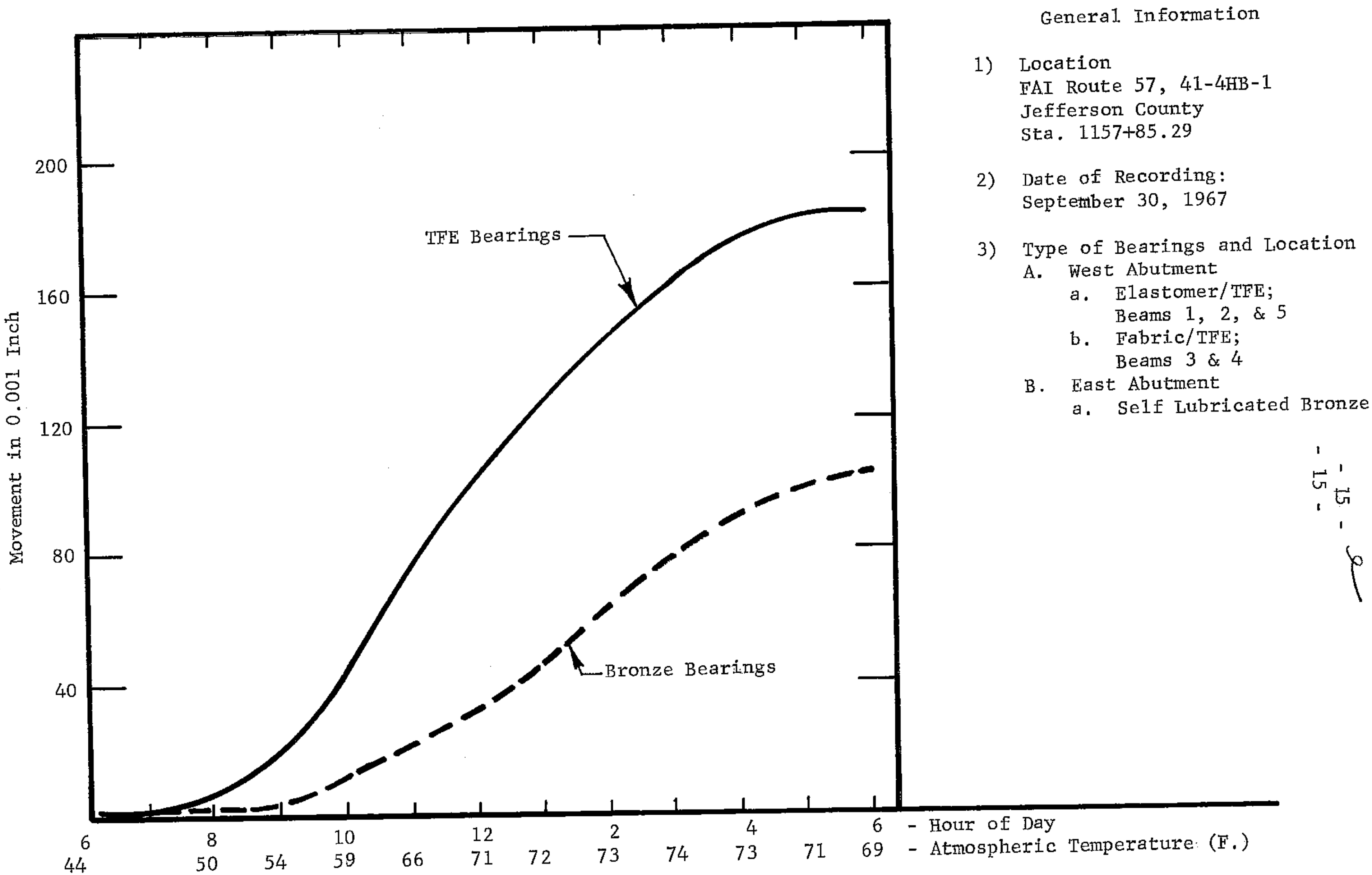

Figure 9. Longitudinal Thermal Movement of Bridge at Bearings (Field Test).

Figure 9. Longitudinal thermal movement of bridge at bearings (field test).

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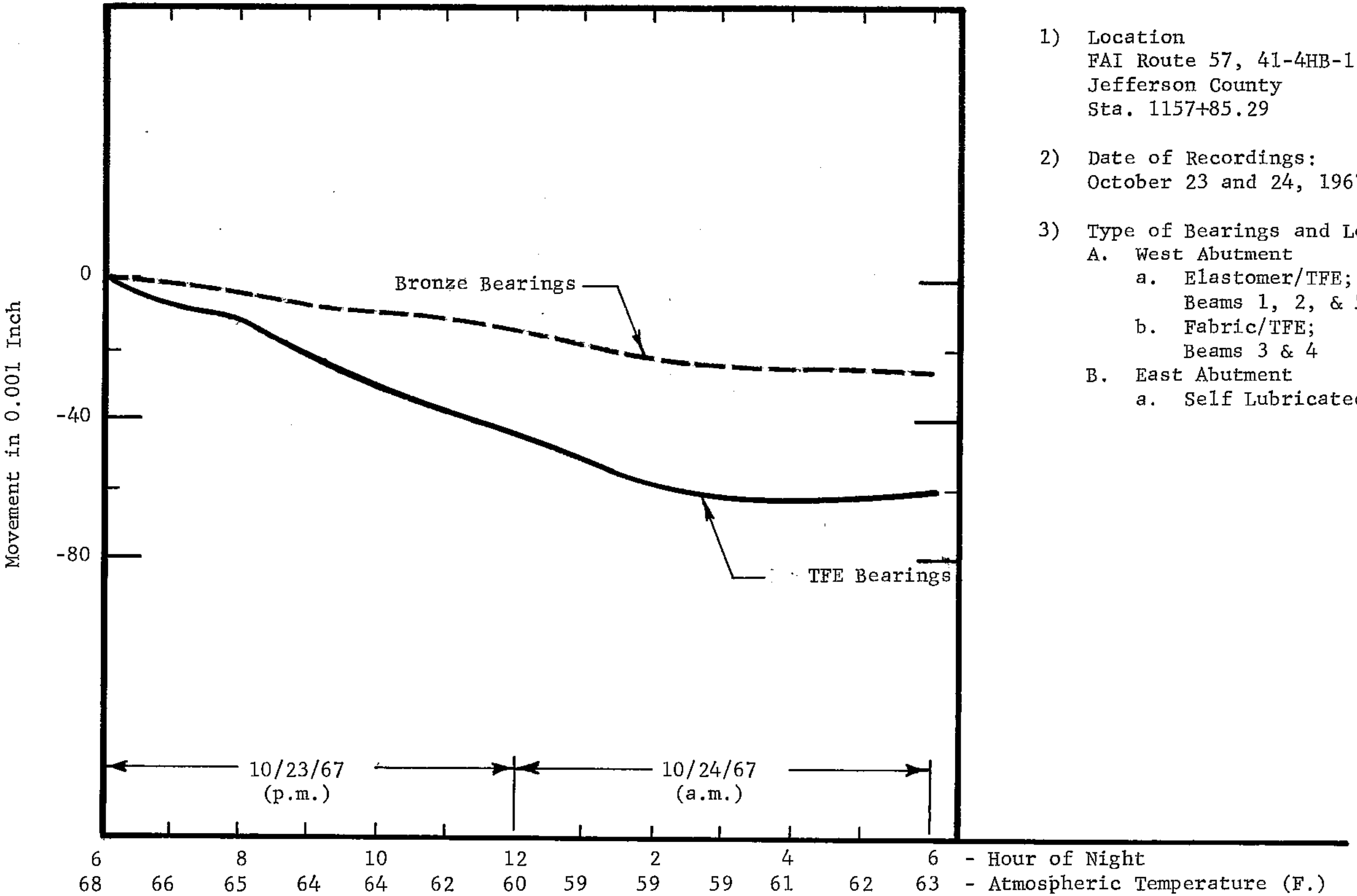

General Information

1) Location
   FAI Route 57, 41-4HB-1
   Jefferson County
   Sta. 1157+85.29

2) Date of Recordings:
   October 23 and 24, 1967

3) Type of Bearings and Location
   A. West Abutment
      a. Elastomer/TFE;
         Beams 1, 2, & 5
      b. Fabric/TFE;
         Beams 3 & 4
   B. East Abutment
      a. Self Lubricated Bronze

Figure 10. Longitudinal Thermal Movement of Bridge at Bearings (Field Test)

Figure 10. Longitudinal thermal movement of bridge at bearings (field test).

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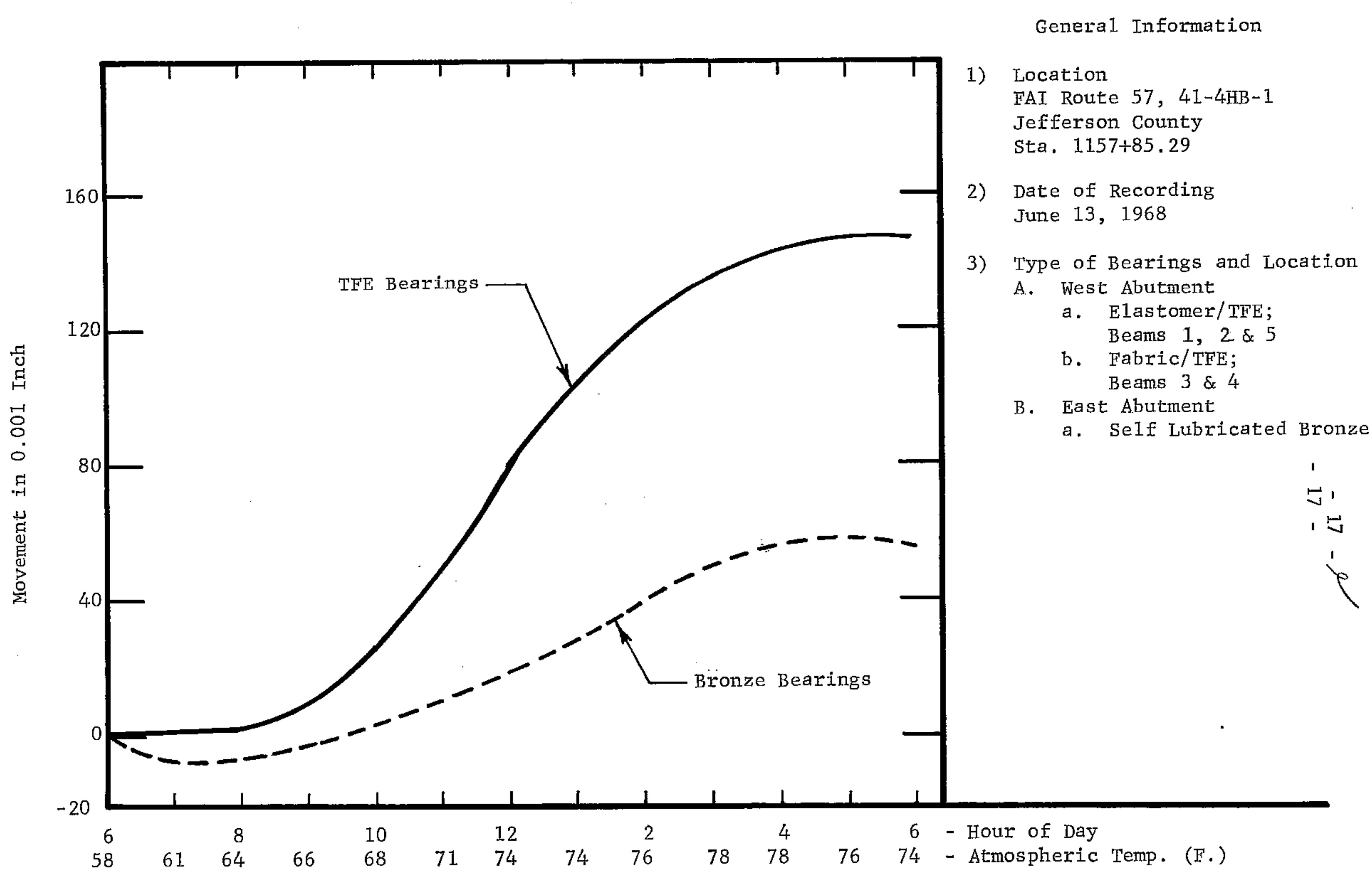

Figure 11. Longitudinal Thermal Movement of Bridge at Bearings (Field Test).

Figure 11. Longitudinal thermal movement of bridge at bearings (field test).

The essential elements of the drive mechanism are the belt-driven eccentric and the connecting rod between the eccentric and the lower load plate which resolves rotational motion to a translational displacement and a 1/3 horsepower motor which powers the system. The connecting rod is instrumented with SR-4 strain gages for measuring the lateral forces inducing translational movement. This information is used for determining frictional resistance of the sliding surface of the bearing assemblies.

A Sandborn single channel system consisting of a power supply, preamplifier, driver amplifier, and single channel hot stylus recorder was used for monitoring and recording the horizontal loads required to translate the bearings. The data acquisition system also included an automatic sequential timer for periodic and intermittent recording of the horizontal loads during periods of continuous testing. An automatic counter was used for registering the number of cycles occurring with each test period.

Test Procedures

The laboratory program consisted of two types of tests for evaluating the possible use of TFE bearings for highway bridges. The program included (1) repetitive translational tests for analyzing the durability or fatigue life of the bearing units and (2) slip tests for determining the coefficient of friction for various compositions of TFE and filler materials.

Fatigue Tests

A 20-year service life was established as a basis for evaluating the performance and the durability of the laboratory test specimens. One year of service life is interpreted as the equivalent of 365 complete translation cycles of testing. From this criterion the selected minimum number of translational cycles needed to determine the fatigue life and to evaluate the long-term performance and durability of the bearings was 7000. The frequency of translation based on two-directional displacement is approximately two cycles per minute. With this rate of cycling each test undergoing 7000 cycles of lateral translation took about 60 hours or 2 1/2 days to complete. If the performance of the bearings could be demonstrated with no evidence of distress or incipient failure during the test period, it was assumed that the predicted service life could be projected to that of the bridge structure.

The test specimens were subjected to horizontal translational movements measuring 1.28 inches maximum displacement at various vertical load increments based on the design unit pressures as determined from the dead load reactions calculated for the experimental bridge installation. The range of load levels for which the bearings were tested was limited to the maximum capacities recommended for the materials tested. The load increments generally used for the testing were design, design plus 50 percent, and design plus 100 percent vertical dead load. The load level representing design dead load plus 50 percent approximates the combination design dead plus live load conditions in the field.

Live load rotational effects were also considered at the beginning of the test program. The original testing apparatus included a drive mechanism for inducing rotational movements at a rate of six cycles per minute. A malfunction in this device, however, developed within the early part of the testing program and became a continual maintenance problem. Finally, it was decided to discontinue this feature of the test.

During the testing of the first few pads the imposed live load rotational effect appeared to have little influence on the performance of the bearings. Because of the apparent insignificant effect of live load rotation, tests involving the rotational movement were suspended in lieu of later tests incorporating the more critical condition of nonparallel loaded surfaces. The condition of non-parallel surfaces was induced by using shims to raise one end of the upper load plate at slopes of 0, 2 1/2, and 5 percent with the horizontal plane.

Slip Tests

Slip tests were conducted to compare the frictional properties of various TFE materials under varying conditions of sliding. The horizontal forces needed to induce sliding across the TFE surface were measured in relation to the applied normal pressures, which ranged from 200 psi to 1400 psi. Values for the coefficient of friction were computed on the basis of the maximum frictional forces obtained for the corresponding normal pressures applied to the test specimens.

The data from the slip test were used to compare the frictional properties of both filled and unfilled TFE materials, to study the change in frictional properties during repetitive translational cycling, and to determine the effect of contaminated TFE surface conditions.

LABORATORY TEST RESULTS

In the initial stages of this study the filled TFE was considered to be the most likely material suitable for application as bridge bearings. Consequently, the earlier tests were conducted on TFE with 25 percent glass fiber filler. As the study progressed, tests were made on 15 percent glass-filled TFE and unfilled TFE to determine the effect of varying amounts of glass fiber filler on the performance of the bearings. The results of this comparison, as presented later, show that the performance of the unfilled samples under the test conditions was significantly better than that of the filled specimens.

The test procedures consisted of measuring the horizontal forces required to slide the TFE sample bearings which were subjected to normal loads ranging from 200 psi to 1400 psi. The values recorded were the breakaway or maximum static forces required to induce sliding between the bearing interfaces. From this information the coefficients of friction at the various load levels were computed.

Values of the horizontal forces and the coefficients of friction for the unfilled TFE and the 15 and 25 percent glass-filled TFE samples are presented in Figures 12 through 14. These charts show a variation in the measured parameters with normal load with the friction coefficient decreasing with increasing vertical pressure. Also indicated on each graph is the variation of the coefficient of friction from sample to sample among specimens of like composition. The maximum and minimum values of the horizontal forces and the coefficients of friction for each specimen type are given in the charts. Other similar samples tested fell between these limits.

The curve of minimum values in each figure represents unused specimens which previously had not been tested. The test samples which yielded the maximum values for horizontal load and coefficient of friction had been subjected to at least 7000 testing cycles prior to this part of the testing program. The curves representing the minimum values in all three cases are similar, indicating that the coefficient of friction for the unused specimens are equivalent regardless of the amount of glass filler used. At the other extreme the curves for the maximum values show a considerable difference between the filled and the unfilled specimens, although not much variation is apparent between the 15 and 25 percent glass-filled samples (Figure 15). This indicates that a buildup of frictional forces occurs with increased wear of the glass-filled surface layers.

The primary reasons for adding filler material to TFE are to increase the resistance of the pure TFE to creep under sustained load and to improve the

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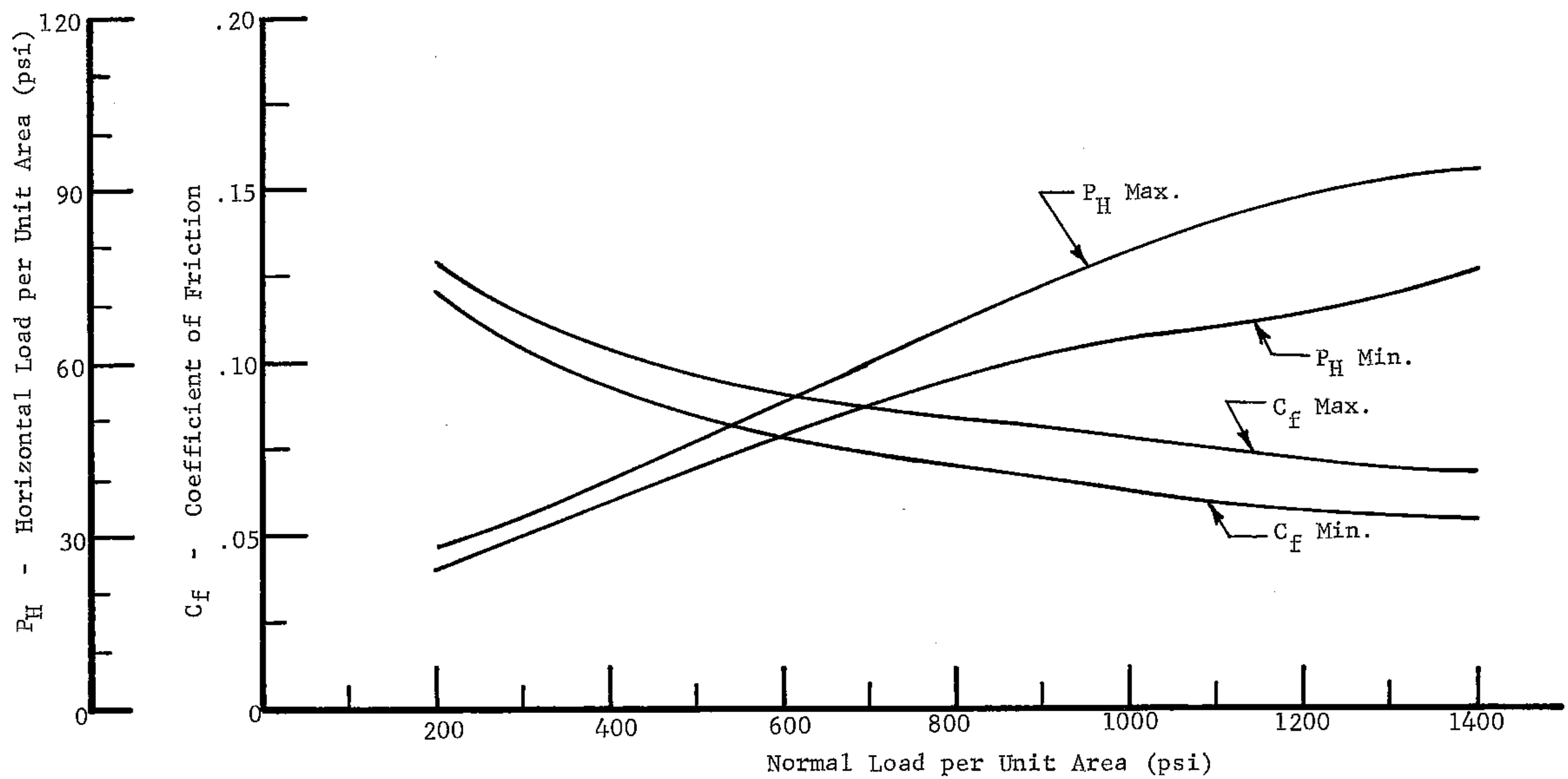

Figure 12. Coefficient of Friction and Horizontal Unit Load vs. Vertical Pressure - Unfilled TFE

Figure 12. Coefficient of friction and horizontal unit load vs. vertical pressure - unfilled TFE.

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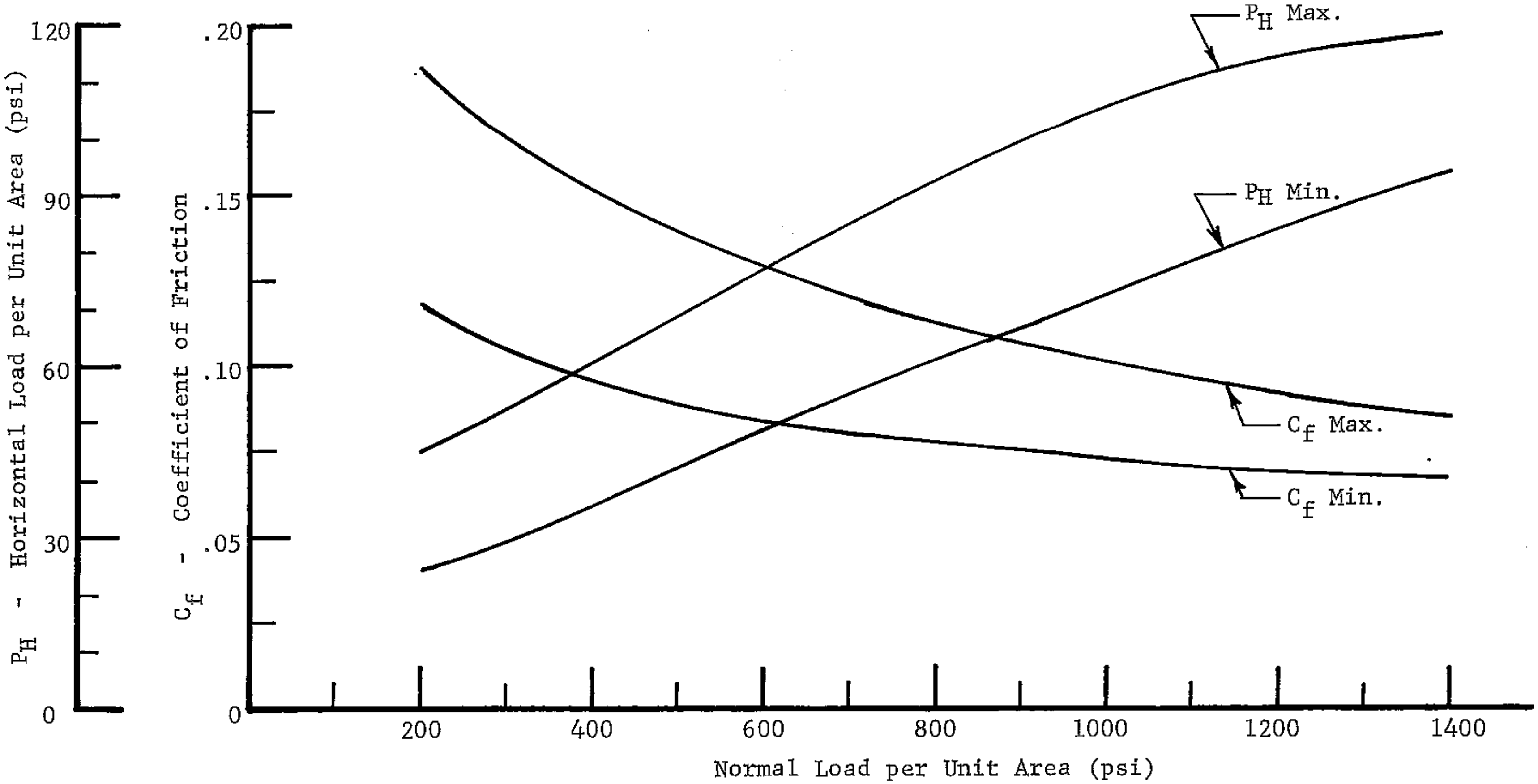

Figure 13. Coefficient of Friction and Horizontal Unit Load vs. Vertical Pressure - 15 percent Glass Filled TFE

Figure 13. Coefficient of friction and horizontal unit load vs. vertical pressure - 15 percent glass-filled TFE.

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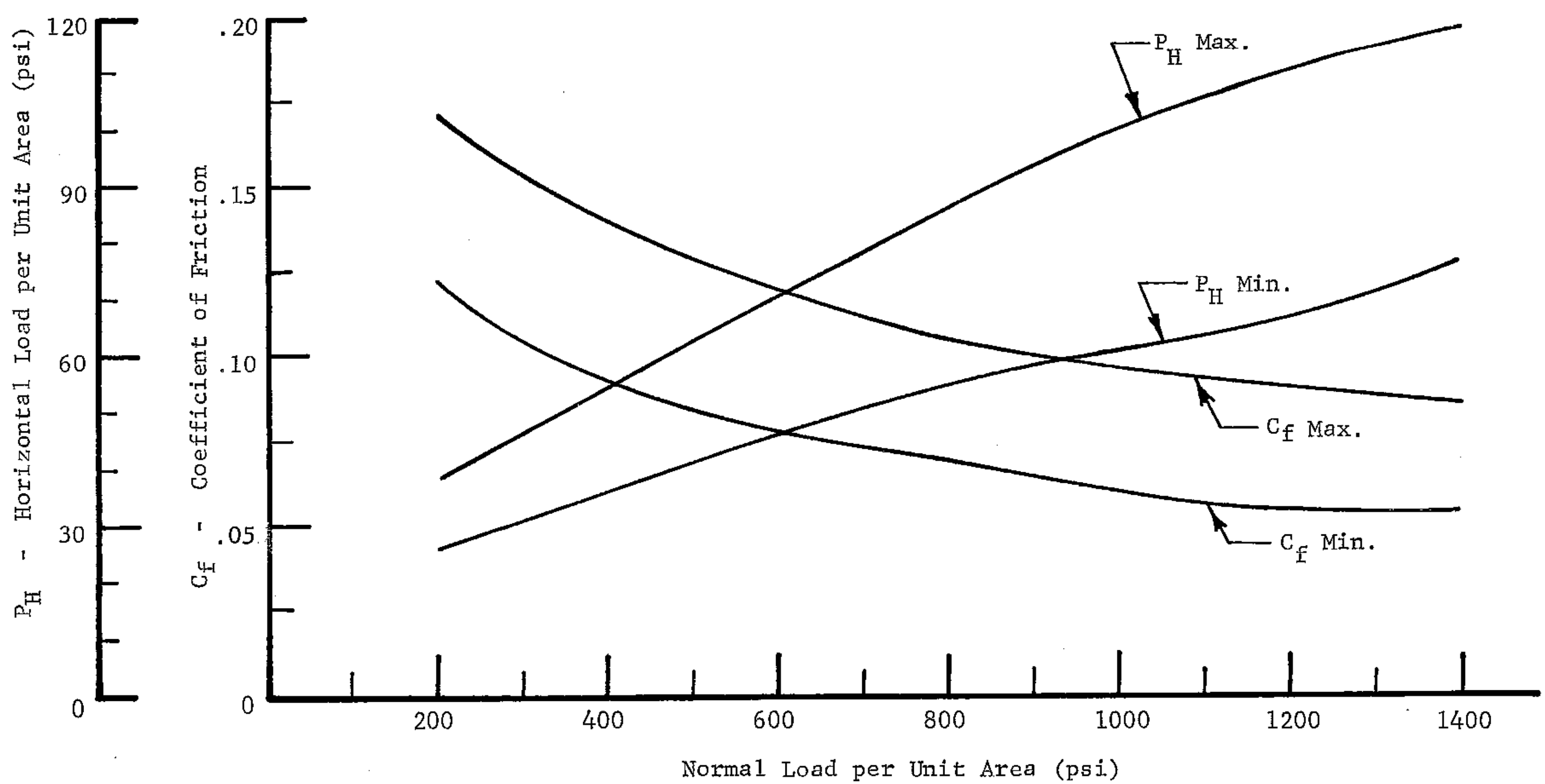


Figure 14. Coefficient of friction and horizontal unit load vs. vertical pressure - 25 percent glass-filled TFE.

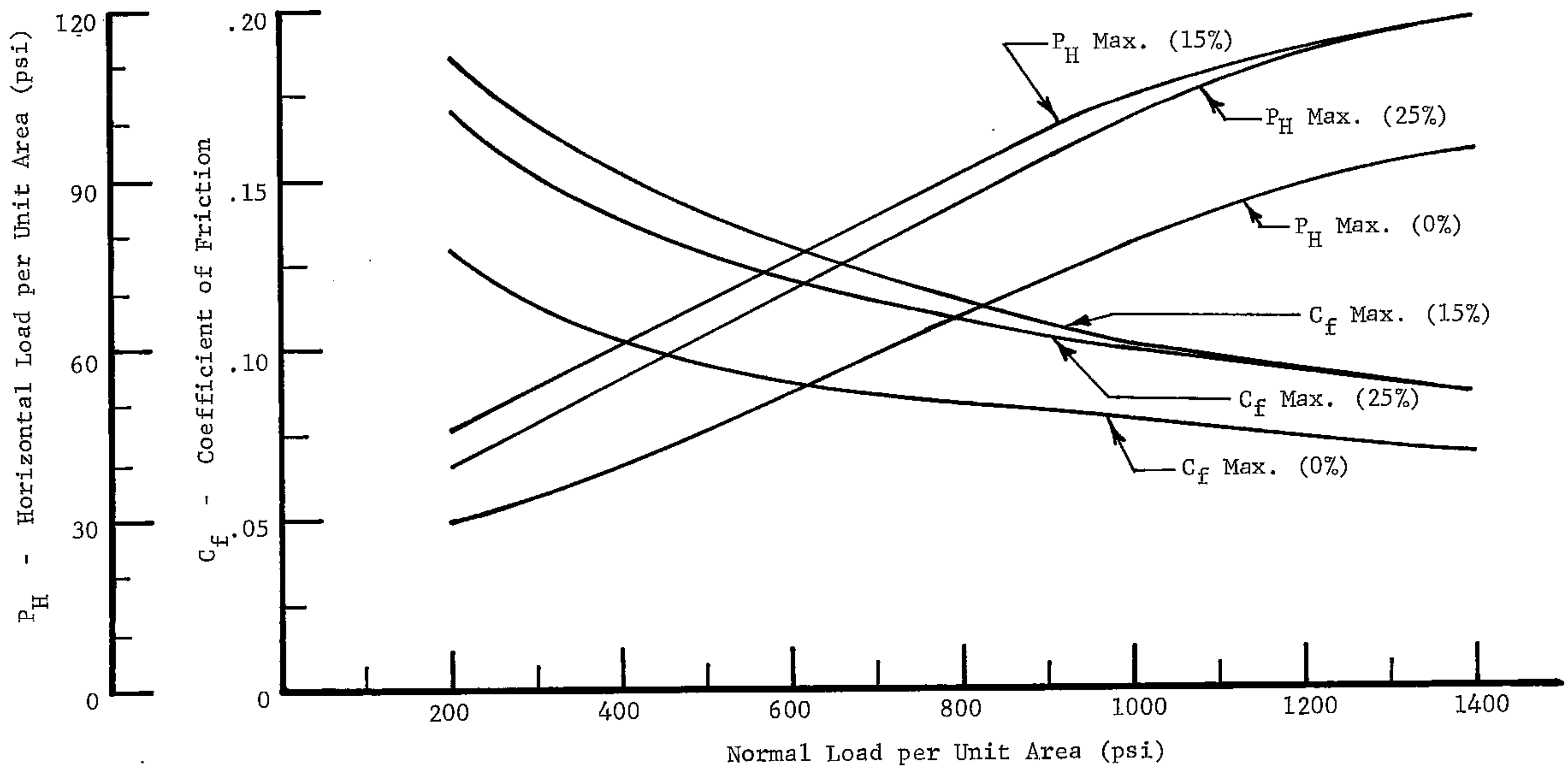


Figure 15. Maximum Coefficients of Friction and Horizontal Unit Loads vs. Vertical Pressure - 0, 15, and 25 percent Glass Filled TFE

Figure 15. Maximum coefficients of friction and horizontal unit loads vs. vertical pressure - 0, 15, and 25 percent glass-filled TFE.

wearability of the material when subjected to high speed moving loads. Although some applications of the TFE material may require that a reinforcing filler be used, it is improbable that the loads of 400 to 800 psi and the rate of movements on a typical bridge will approach the magnitude necessary to cause a significant creep or wear effect on the TFE.

Since the results of this series of tests indicate that a significant reduction in the coefficient of friction can be achieved by using unfilled TFE, further study of the pure material will be made. In order to investigate the cold flow characteristics of both filled and unfilled TFE under static load conditions, a creep rack was built, and samples containing 0, 15, and 25 percent glass filler were installed (Figure 16). The compressive load level applied to the specimens range from 400 psi on 6- x 18-inch rectangular samples to 1600 psi on circular samples 5.85 inches in diameter. The duration of the test is estimated to be five years with annual inspections made to determine the creep characteristics of the various compositions of the filled and unfilled TFE materials.

One pair of tests was made to compare the coefficients of friction of TFE sliding against TFE and TFE sliding against stainless steel with a 16 RMS finish. In both cases the TFE surfaces were reinforced by a 25 percent glass fiber filler. The results of this test, which are presented in Table 1, indicate no significant difference in the friction coefficient for the two sliding surfaces.

Effect of Backing Material

The samples tested during this phase of laboratory work consisted of various combinations of TFE bearings backed with either rubber impregnated fabric or elastomeric rubber composition. The test specimens included samples with and without stainless steel laminates bonded between the TFE facing and elastomeric or

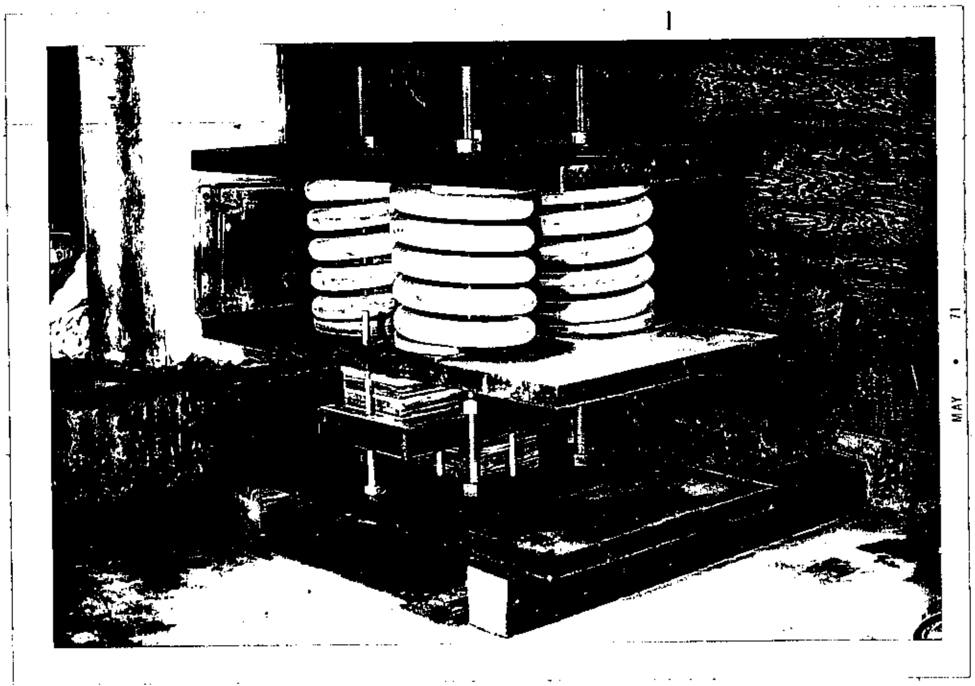


Figure 16. Creep rack (43 kip capacity).

TABLE 1.

COEFFICIENTS OF FRICTION FOR TFE SLIDING AGAINST TFE AND STAINLESS STEEL

Vertical Pressure (psi)	C_f TFE vs. TFE	C_f TFE vs. Stainless Steel
200	.13	.14
400	.12	.12
600	.10	.11
800	.10	.10
1000	.09	.09
1200	.08	.08
1400	.08	.07

fabric backing. Tests of the self-lubricating bronze plate were also conducted so that a comparative evaluation could be made with the samples utilizing the TFE sliding surface.

Rubber Backing

The bearings included in this section were tested for performance and durability to determine the effect of various types of rubber backing and combinations of rubber backing with stainless steel interlayers. Parameters such as hardness of the rubber and shape factor of the elastomeric backing were considered during the investigation. A list of the rubber-backed bearing assemblies tested is presented in Table 1, Appendix A.

Except for two specimens which were backed by adiprene of 80 hardness, all samples were backed by neoprene of 50, 60, or 70 hardness (Shore A durometer). The shape factor of an elastomeric pad is the ratio of the surface area of the bearing to the perimetrical edge area. This factor provides an indication of the deflection characteristics of the bearing under compressive loads with a lower shape factor indicating more deflection of the bearing pad. Shape factors of 2.7 and 5.4 were included in this series of tests. All TFE surfaces with rubber backing had surface areas measuring 5 x 6 inches and were reinforced with 25 percent glass filler.

Curves showing the coefficient of friction versus number of translational cycles at load levels of 400 psi, 750 psi, and 1000 psi for specimens N1, N2, and N3 are presented in Figures 17, 18, and 19. The lowest and most consistent values of the friction coefficient at all load levels except 1000 psi were recorded for the N2 sample. As indicated in Table 1, Appendix A, specimens N2 and N1 were identical except for the opposing sliding surface, while the only difference

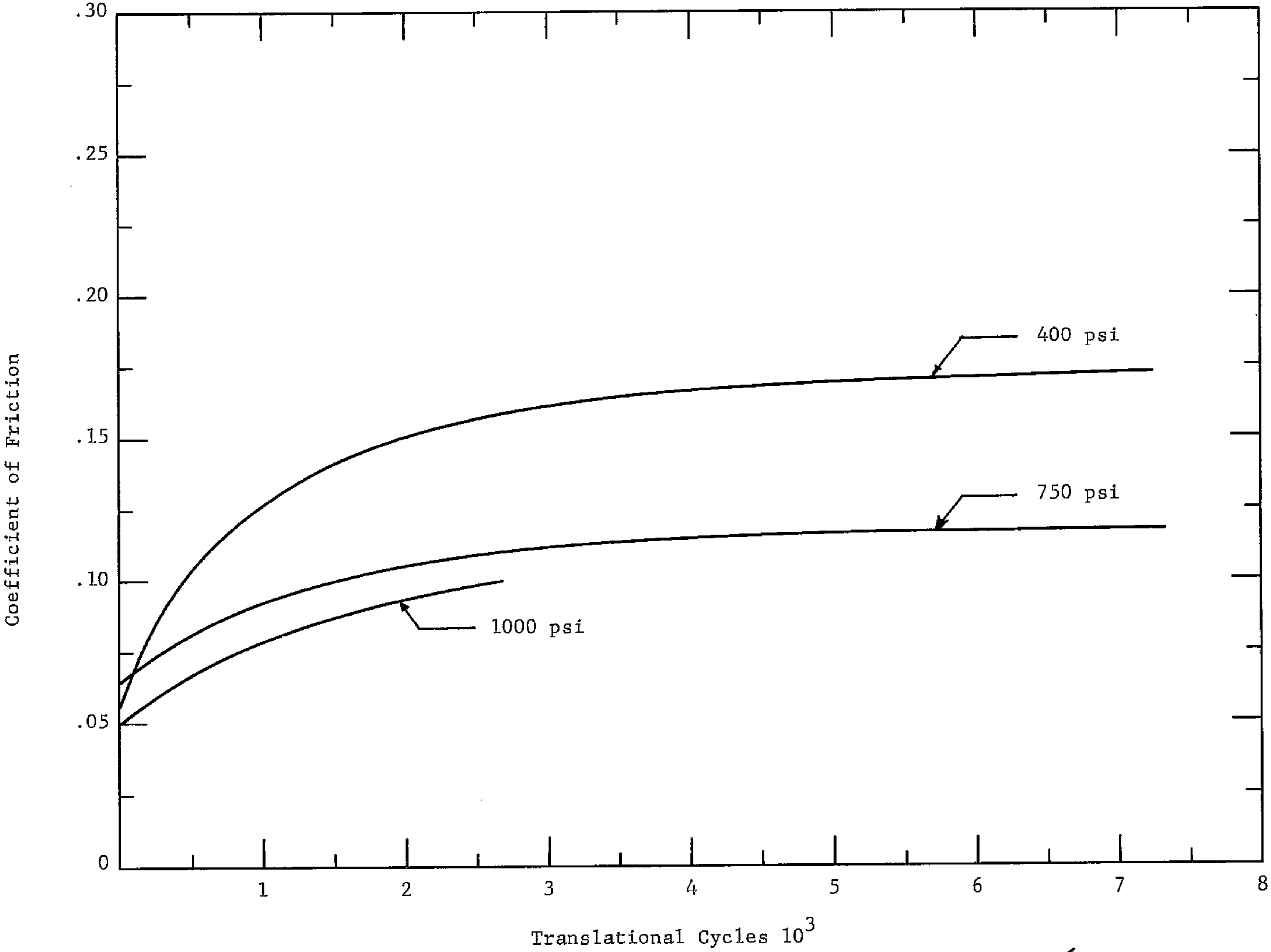


Figure 17. Translational Tests of Specimen N1 Under Normal Load

Figure 17. Translational test of specimen N1 under normal load.

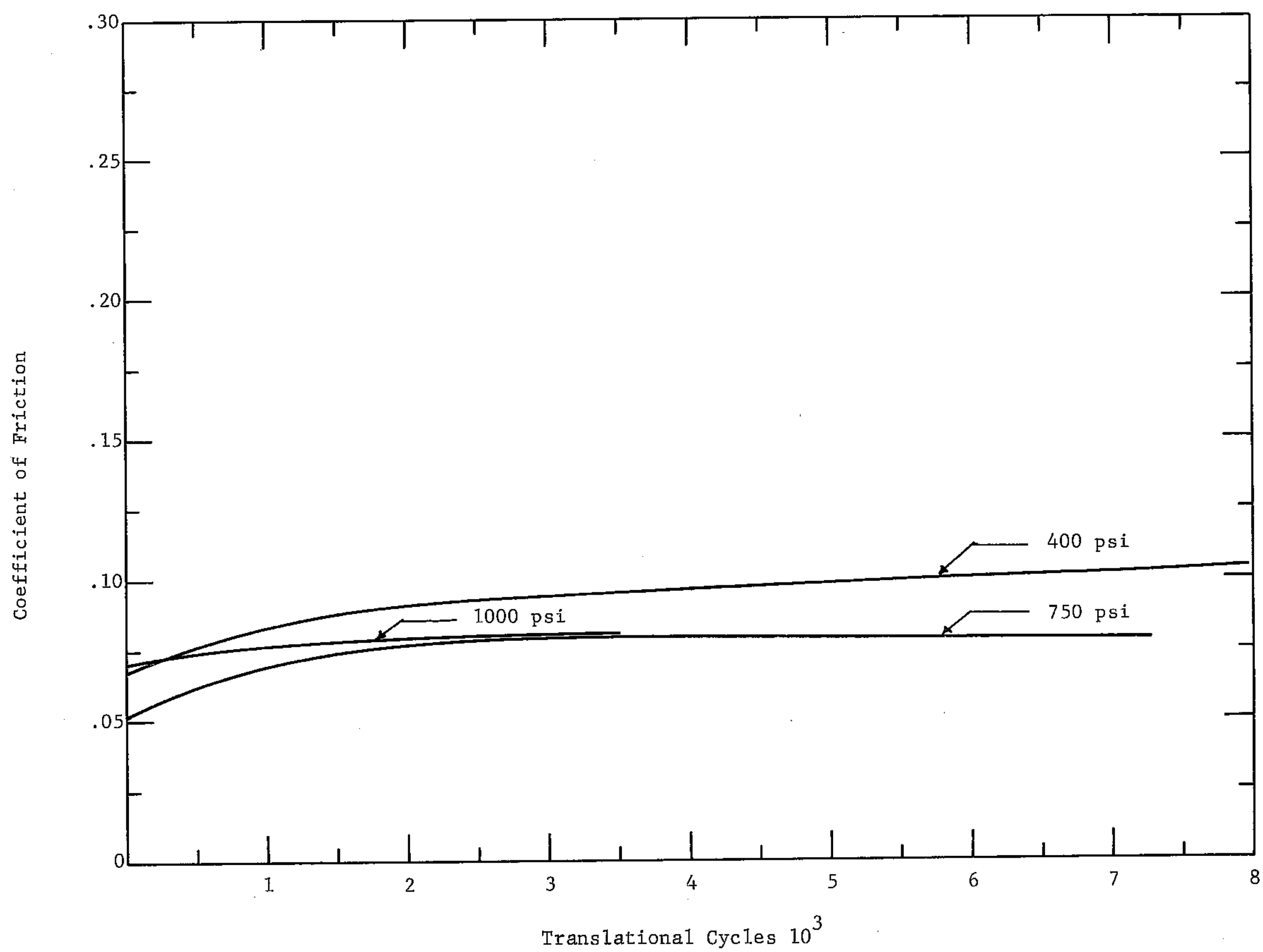


Figure 18. Translational test of specimen N2 under normal loads.

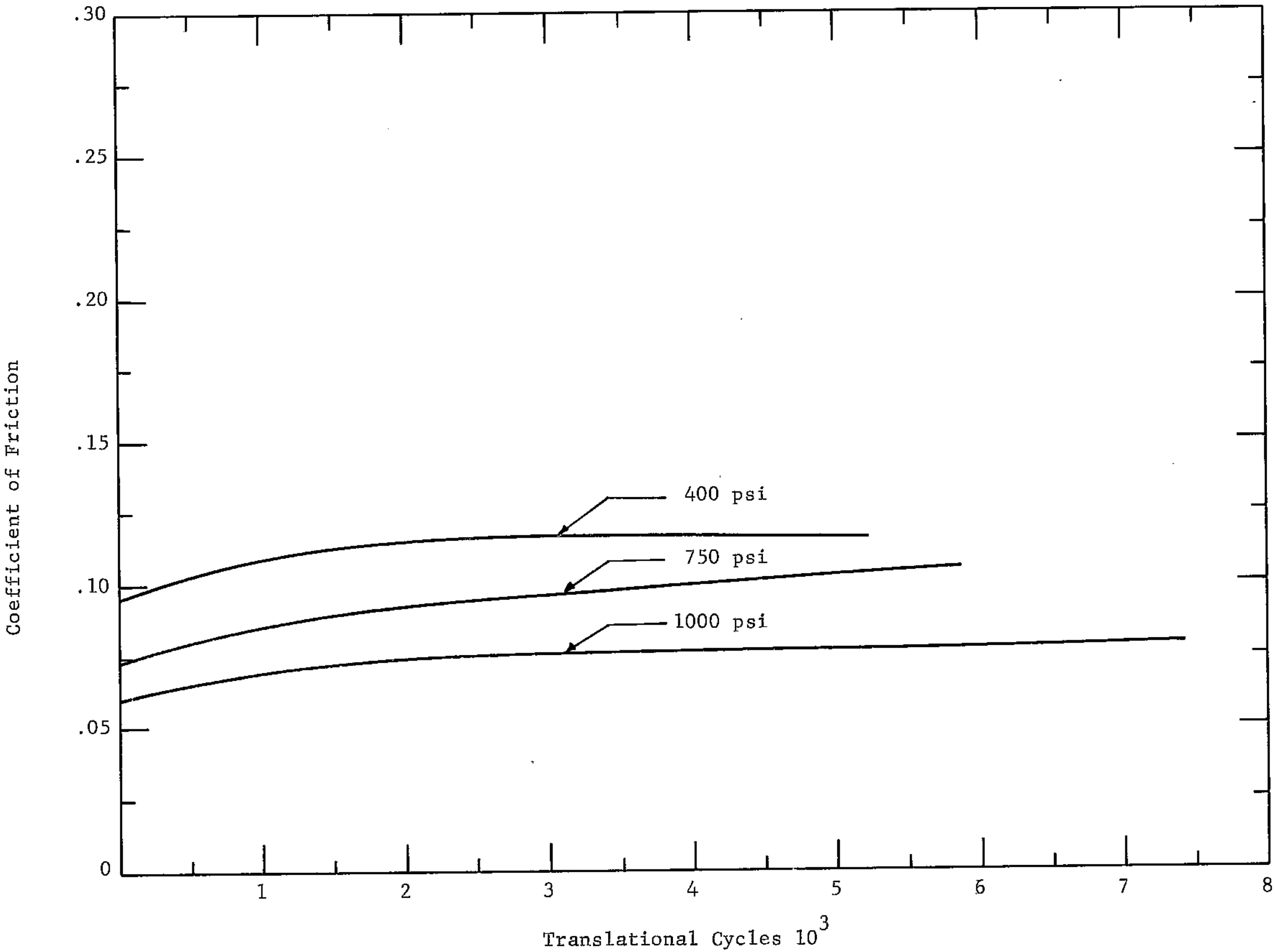


Figure 19. Translational Tests of Specimen N3 Under Normal Loads

Figure 19. Translational test of specimen N3 under normal loads.

between specimens N2 and N3 was the backing configuration. From these results alone, it would appear that the coefficient of friction of N2 was lower than N1 because of the difference in the opposing sliding surfaces. N2 was sliding against TFE bonded to stainless steel backed by 1/2-inch-thick neoprene, while N1 was sliding against polished stainless steel. Other tests, however, indicated little difference in the coefficient of friction between stainless steel and TFE (Table 1), while the difference between samples with and without the neoprene backing for the opposing sliding surface was substantial (Figure 20). The lower coefficient of friction recorded for the N2 sample is believed to be caused by the resiliency of the neoprene-backed upper pad. The increased flexibility of the upper pad possibly results in a more uniform load distribution across the face of the lower element.

Excessive bending of the neoprene-backed top elements was observed when a 1/2-inch rubber backing material was used in conjunction with the thin steel sheet (Samples N2 and N3). The top component which is longer and wider than the lower element was designed to accommodate maximum expansion and prevent contamination of the lower element. The top component, being larger, was subject to bending moments developing in that portion of the upper pad which extended beyond the edge of the lower element. The thin steel sheet between the TFE and rubber materials was found to be inadequate for resisting the moment, and curvature of the top component would develop as the vertical loads were increased. In order to have minimized the curvature, the steel laminate should have been analyzed as a base plate subject to unequal load distribution and designed accordingly. Because of the bending of the upper component, the possibility that the edges of the smaller bottom element might plow into the surface of the upper pad as movement occurred was considered. In order to determine the extent to which this plowing affects the horizontal force required to move the bearing, the specimens were tested with the neoprene backing

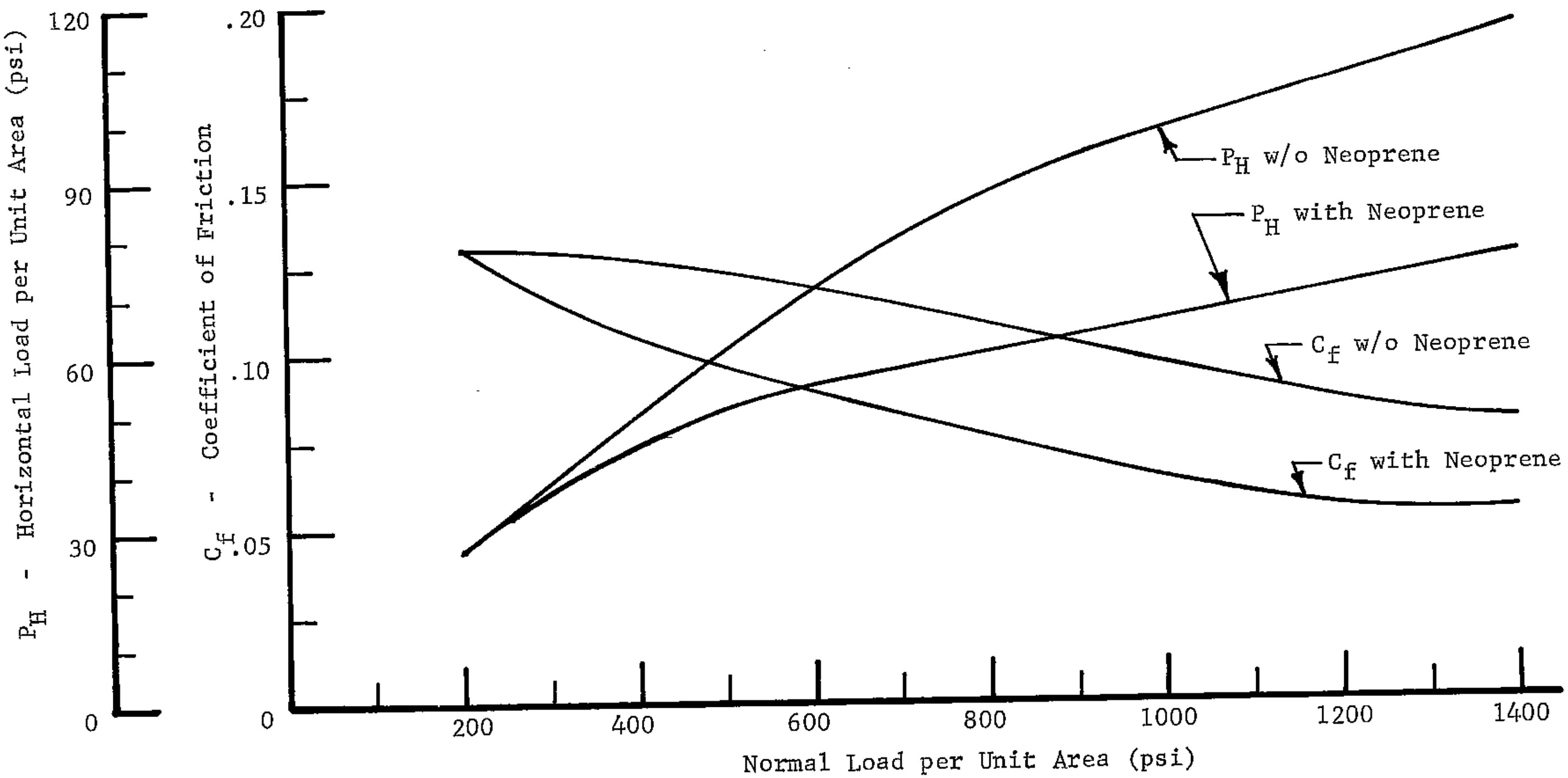


Figure 20. Coefficient of friction and horizontal load vs. vertical pressure - TFE against TFE with neoprene backing and TFE against TFE without neoprene backing (TFE 25 percent glass filled).

on both the upper and lower elements. The test was then repeated with the neoprene backing removed from the upper pad. Visual observations during the test indicated that much less bending occurred in the upper pad with the neoprene backing removed. The results of this test as plotted in Figure 20 indicate, however, that less force was required to slide the bearing with the neoprene backing in place, resulting in a lower coefficient of friction for the neoprene-backed pad. Apparently, the expected plowing effect does not exist despite the increased bending of the upper pad.

Of the six N2 and N3 samples tested, two specimens failed by a horizontal separation of the neoprene backing near the midheight of the upper component. The remaining four samples showed no evidence of physical damage, and none of the tested specimens indicated inelastic deformation of the steel laminates. Despite the decreased coefficient of friction recorded for the rubber-backed top pad, the excessive deflection and the horizontal separation of two of the six tested samples were considered sufficient cause to eliminate this type of sliding surface from further consideration.

Permanent deformation of specimens (N3) without a steel laminate between the TFE sheet and rubber backing was evident after removing the samples from the test. The deformation, however, appeared to have no effect on the performance of the bearings provided that the load was sustained throughout the test. When the load was removed, the rubber would tend to regain its original shape and collapse the nonelastic TFE sheet causing excessive wrinkling of the TFE surface layer (Figures 21 and 22). This type of failure was more critical at the 750 and 1000 psi load levels than at the 400 psi level. The tests indicated that the steel laminate inserted between the TFE and rubber elements was beneficial - especially for the higher load levels. Pads reinforced with a steel sheet had the greatest potential for developing a satisfactory bearing design.

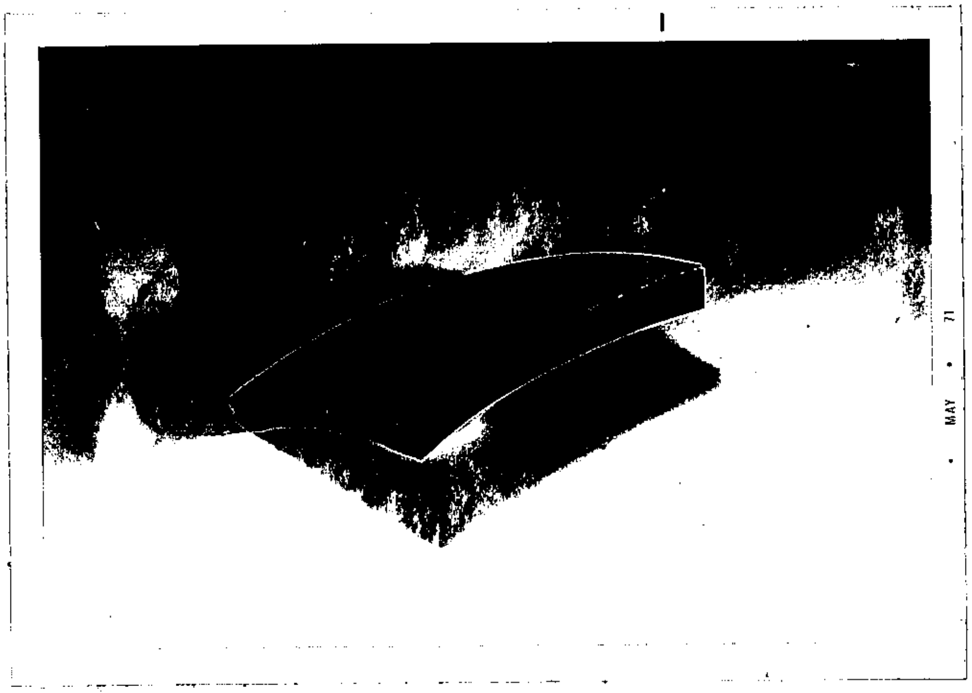


Figure 21. Curvature of N3 specimen after removal of 400 psi test load.

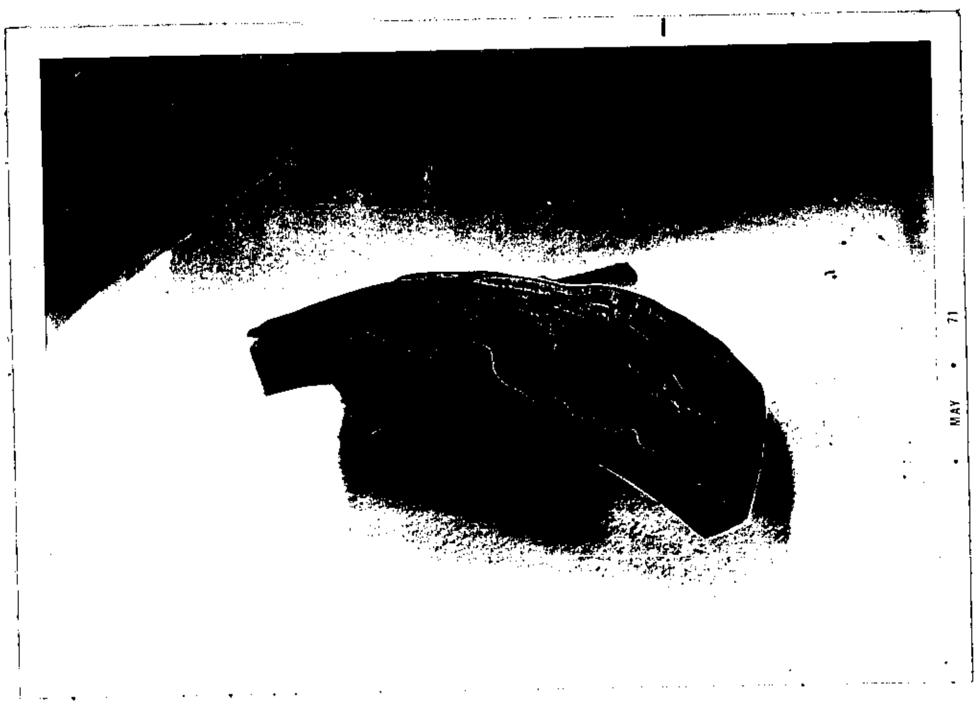


Figure 22. Curvature and wrinkling of N3 specimen after removal of 750 psi test load.

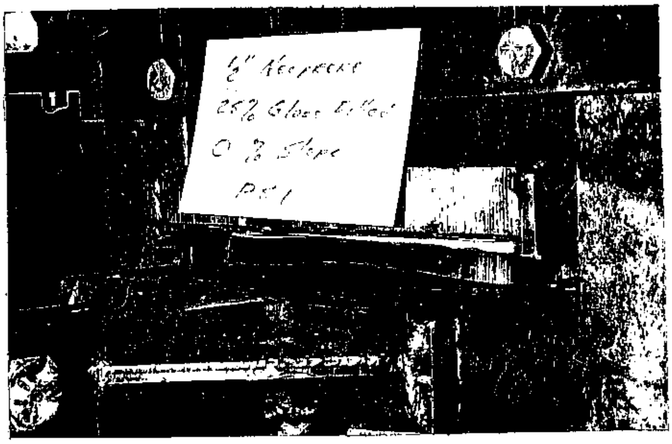
After testing, most neoprene-backed specimens contained surface irregularities in the form of depressed and raised areas in the TFE layer similar to those observed in the field test specimens (Figure 7). Close inspection of the specimens revealed voids in the epoxy used to bond the TFE layers to the stainless steel sheets. Most of the irregularities in the TFE surface layers occurred at the location of these voids in the bonding material. Although the voids represented from approximately 15 to 20 percent of the total bonded area, no failures which could be attributed to poor bonding occurred during the tests.

One of the major aspects in specimen behavior observed during the testing was the horizontal strain induced in the rubber when sliding was impending at the TFE interface. Lateral deflection of the rubber of the bottom components appeared to reach approximately 80 to 100 percent of the rubber thickness. Excessive distortion or lipping of the rubber at the exposed edges also occurred. The distortion became more apparent as the applied vertical loads were increased (Figures 23 through 25). Although this behavior was more severe for the 50 durometer rubber, the strains induced did not appear to have a damaging affect on the bearings.

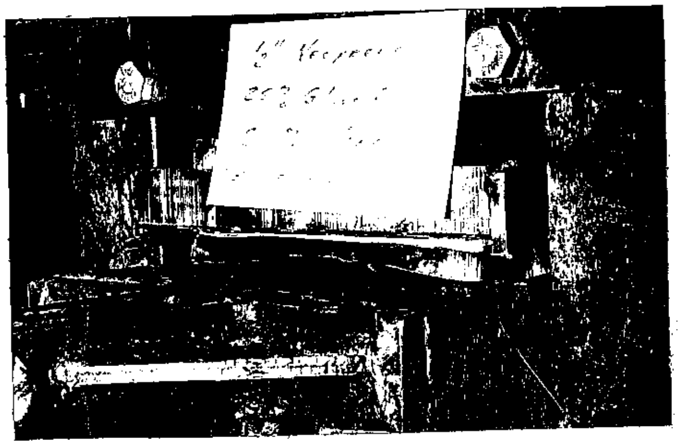
Based on the short term laboratory tests, the excessive horizontal strains for the pure rubber backing materials appeared to have little influence on the performance and durability of the bearings. Certain modifications in the design, however, were considered necessary to minimize the likelihood of structural damage throughout the service life of the bearing. The 50 percent strain limitation currently specified for the design of nonsliding elastomeric bearings was used as a criterion for developing a suitable bearing design.

Various combinations of the basic material elements were tested for evaluating the effect of certain parameters for keeping the horizontal strains within the established limits. The primary factors considered were rubber hardness, shape

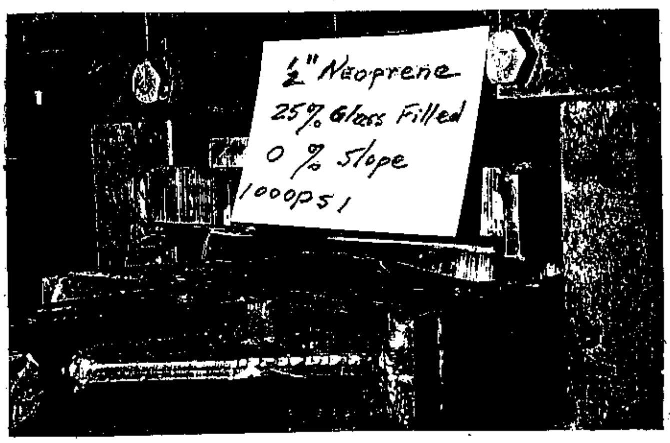
50 HARDNESS - 0 PERCENT SLOPE



500 psi



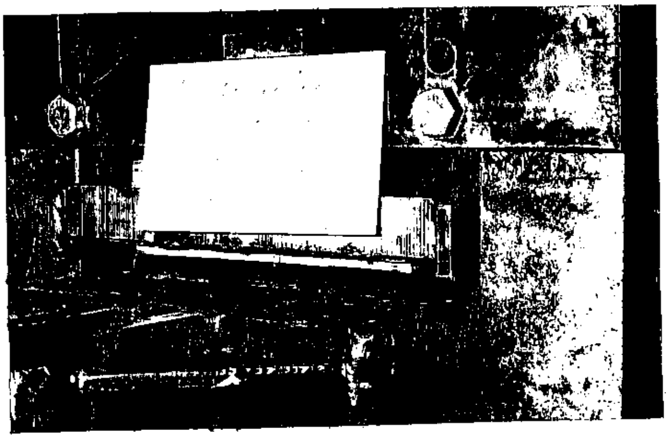
750 psi



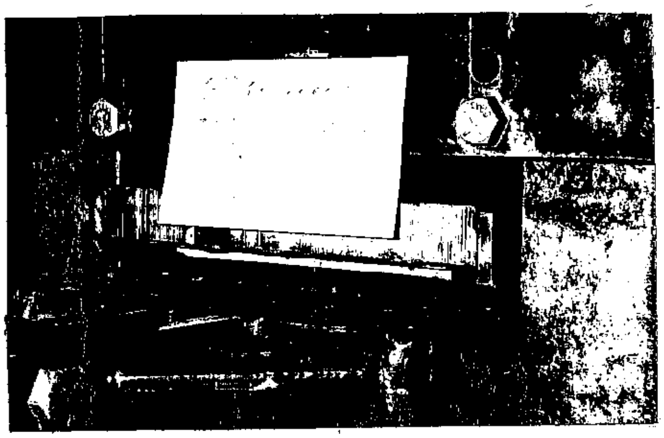
1000 psi

Figure 23. Horizontal load deformation - N1.

60 HARDNESS - 0 PERCENT SLOPE



500 psi

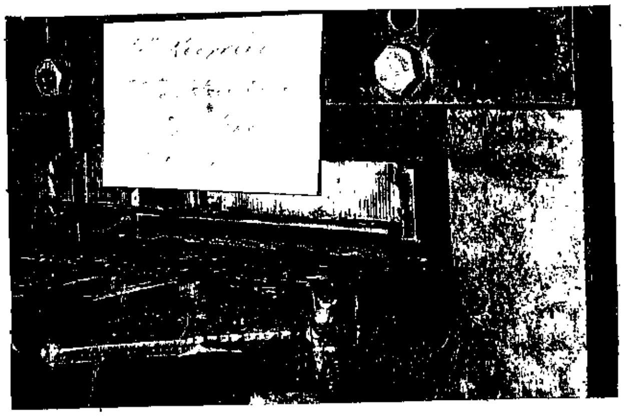


750 psi

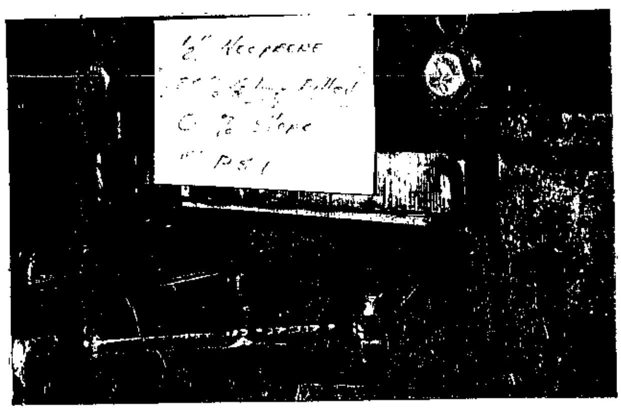
1000 psi

Figure 24. Horizontal load deformation - N4.

70 HARDNESS - 0 PERCENT SLOPE



500 psi

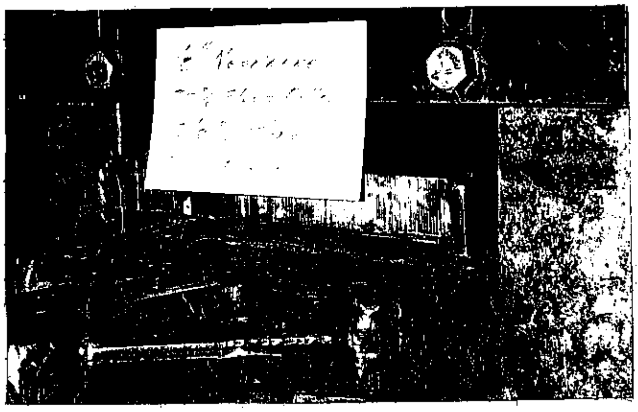


750 psi

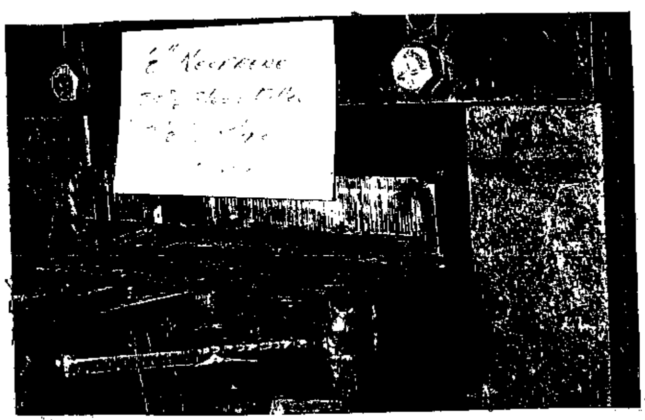
1000 psi

Figure 25. Horizontal load deformation - N5.

70 HARDNESS - 2 1/2 PERCENT SLOPE



500 psi



750 psi

Figure 26. Horizontal load deformation - N5 specimen at 2 1/2 percent slope.

factor, and the effect of an additional steel plate bonded to the bottom surface of the rubber material.

At this point in the testing program, the liveload rotational deflections were suspended from the testing, and a more critical condition of sustained nonparallel load surfaces was introduced to the program. Slopes of 0, 2 1/2, and 5 percent, in conjunction with normal loads of 500 psi and 750 psi, were the loading conditions under which the behavior of the bearings were studied.

Slopes greater than 2 1/2 percent between nonparallel load surfaces appear excessive for the 1/2-inch elastomeric pad. Large edge strains are induced by slopes above this magnitude which could be detrimental to the bearings. Figures 25, 26, and 27 illustrate the degree of deformation of the 70 hardness neoprene at various slopes. A limiting value of 1 1/2 percent is suggested as the maximum slope permitted for the change in grade of a beam between bearing seats. This limitation will provide some factor of safety for construction contingencies such as unevenness of the bearing seat and camber of the prestressed member. For beams with grades in excess of 1 1/2 percent, provisions should be made for rotation in order to distribute the pressure more uniformly over the loaded surface.

Visual observations of the tests indicated that, of all parameters studied, the 70 durometer rubber composition had the most significant influence on the stiffness or shear resistance of the bearing. Increasing the shape factor from 2.7 to 5.4 had the least effect on shear stiffness. The addition of a steel plate bonded to the bottom of the rubber reduced the lipping which previously occurred with the 50 durometer samples, but its use appeared less significant when used in combination with the 70 hardness materials.

From the test data the theoretical effect that the hardness of the neoprene has upon the percent strain of the elastomer was computed and plotted in Figures 28 through 30. The shear strain occurring in an elastomeric bearing is defined as the ratio of horizontal deflection to the thickness of the elastomer. Tests have shown that the stress-strain relationship for neoprene in shear is linear for shear strains up to 50 percent and may be expressed as a modulus. Tests conducted at room temperature by an elastomer manufacturer have established values for this modulus for neoprene of different hardness. Values for this modulus are 110 psi for 50 hardness, 160 psi for 60 hardness, and 215 psi for 70 hardness neoprene. It should be remembered that this modulus is accurate only for strains up to 50 percent. Beyond this level of strain the modulus gives only approximate results, especially for the lower grades of hardness.

Figures 28 through 30 show the percent strain which theoretically would occur in neoprene used for backing TFE bearing surfaces containing 0, 15, and 25 percent glass fiber filler. These curves indicate that the unfilled TFE would produce less strain in the neoprene backing at all load levels. The curves for the 15 and 25 percent filled TFE are similar in all cases and, for practical purposes, may be considered equivalent. Figures 28 through 30 indicate a decrease in percent strain as the hardness of the neoprene is increased. From these results the 70 hardness neoprene would appear to be the most suitable rubber backing material for a TFE sliding surface.

Fabric Backing

Tests were made on specimens backed by rubber impregnated fabric to determine the suitability of this backing material for bridge bearings. A list of the fabric-backed test bearings is presented in Table 2, Appendix A. Samples include different thicknesses of TFE and backing material and various percentages of glass filler. A polished stainless steel surface was used for the opposing sliding element for

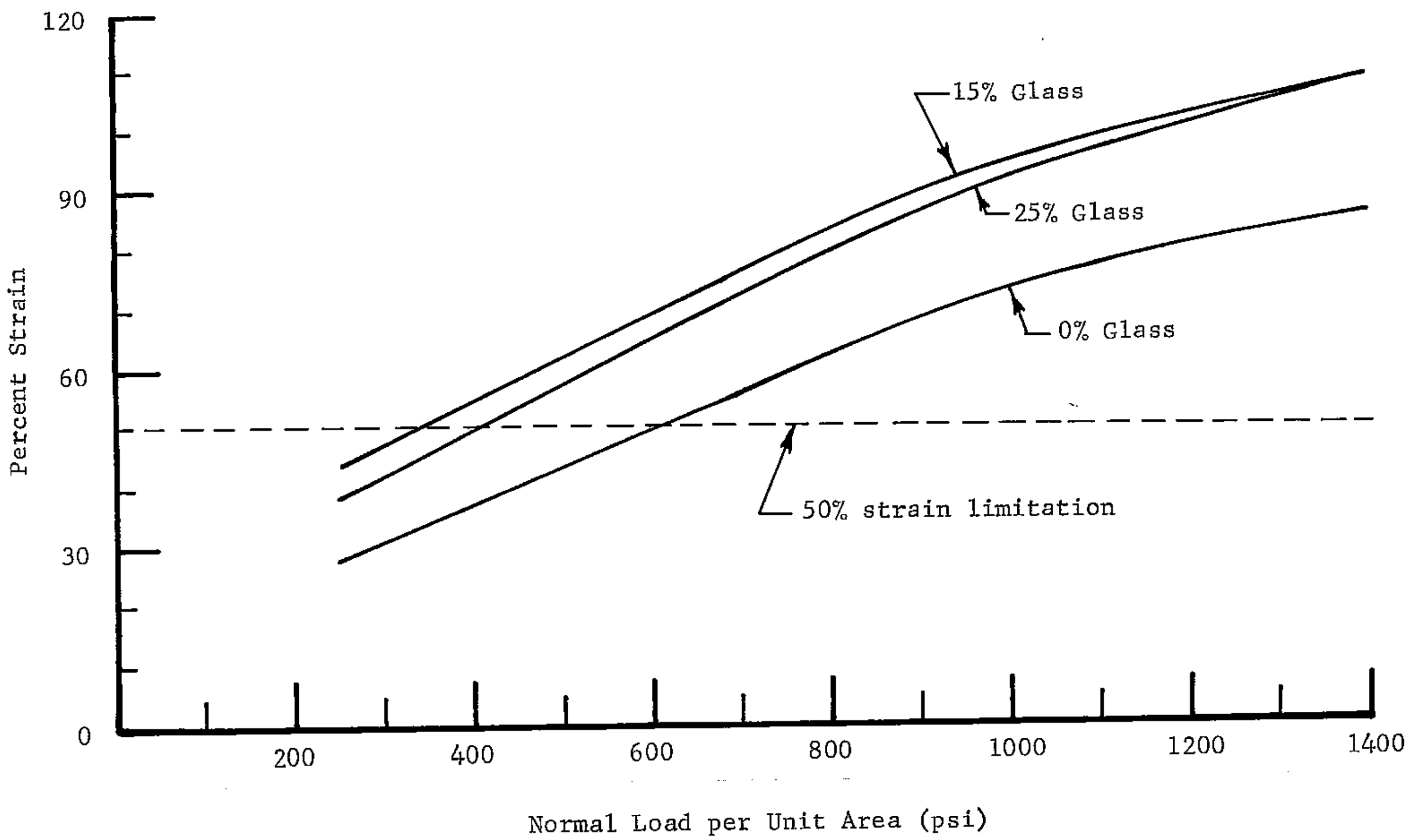


Figure 28. Percent strain vs. vertical pressure - 0, 15, and 25 percent glass-filled TFE backed by 50 hardness neoprene.

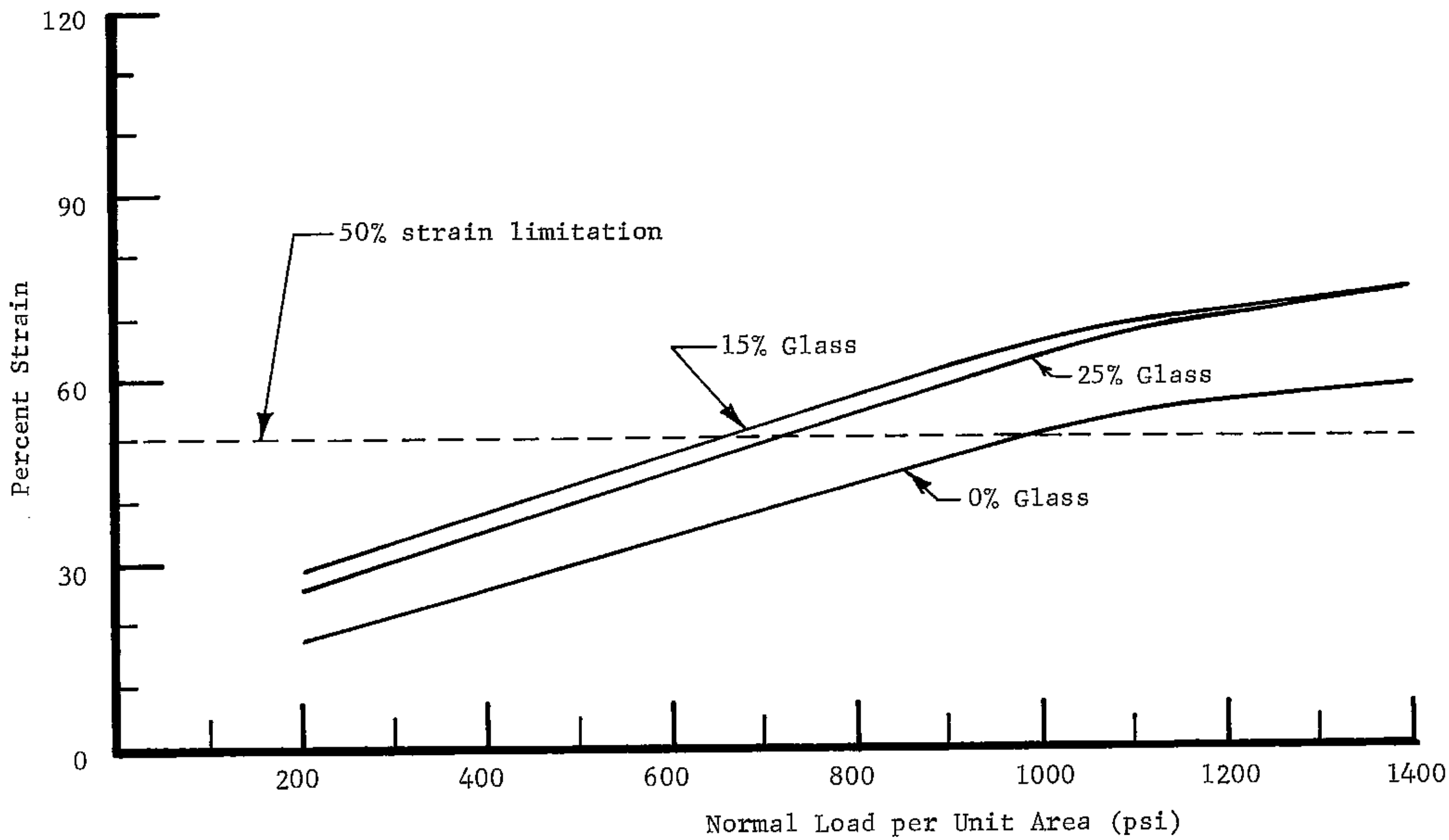
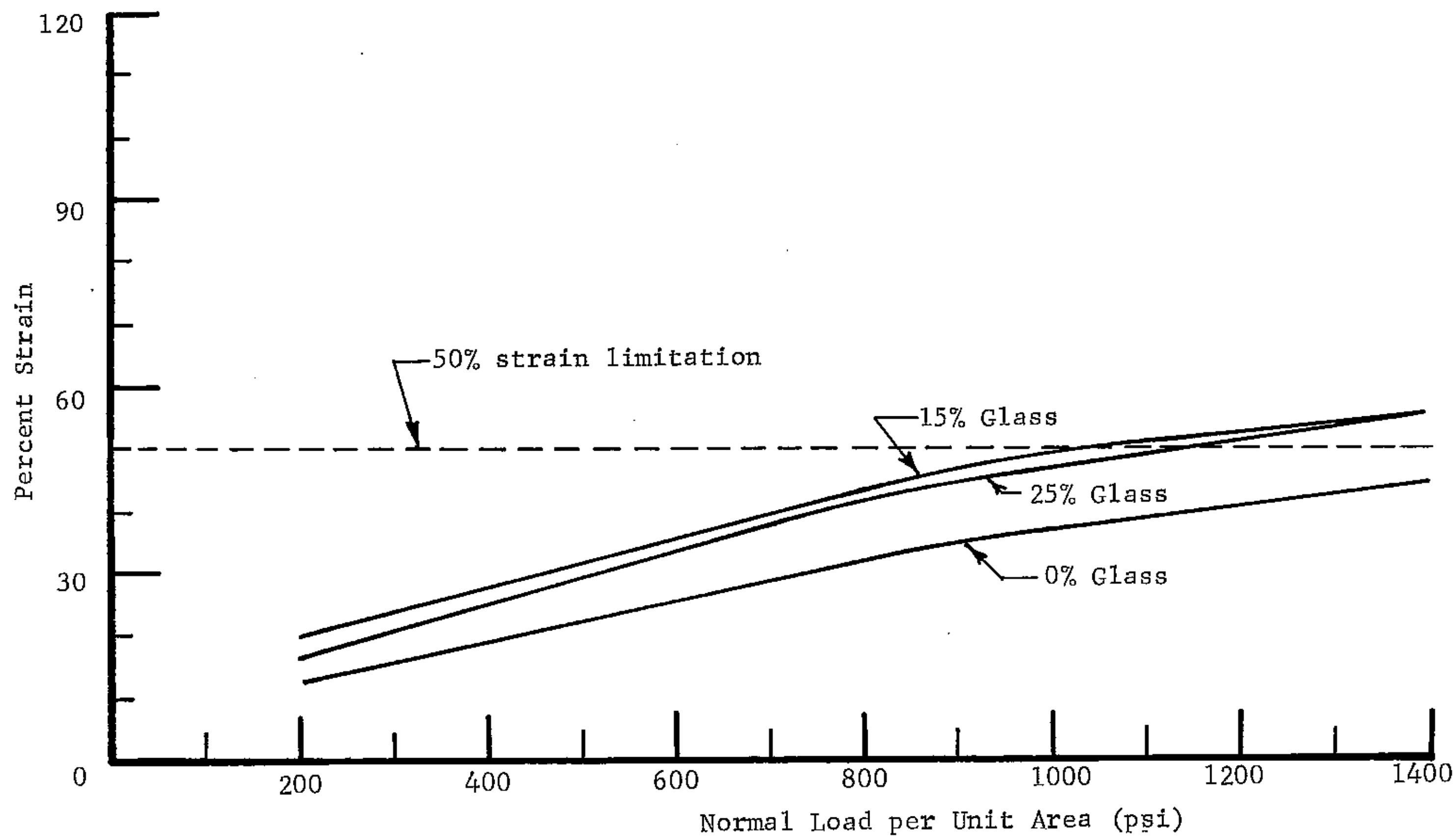


Figure 29. Percent Strain Vs. Vertical Pressure - 0, 15, and 25 percent Glass Filled TFE backed by 60 Hardness Neoprene

Figure 29. Percent strain vs. vertical pressure - 0, 15, and 25 percent glass-filled TFE backed by 60 hardness neoprene.



~~Figure 30.~~ Percent Strain Vs. Vertical Pressure - 0, 15, and 25 percent Glass Filled TFE backed by 70 Hardness Neoprene

Figure 30. Percent Strain vs. vertical pressure - 0, 15, and 25 percent glass-filled TFE backed by 70 hardness neoprene.

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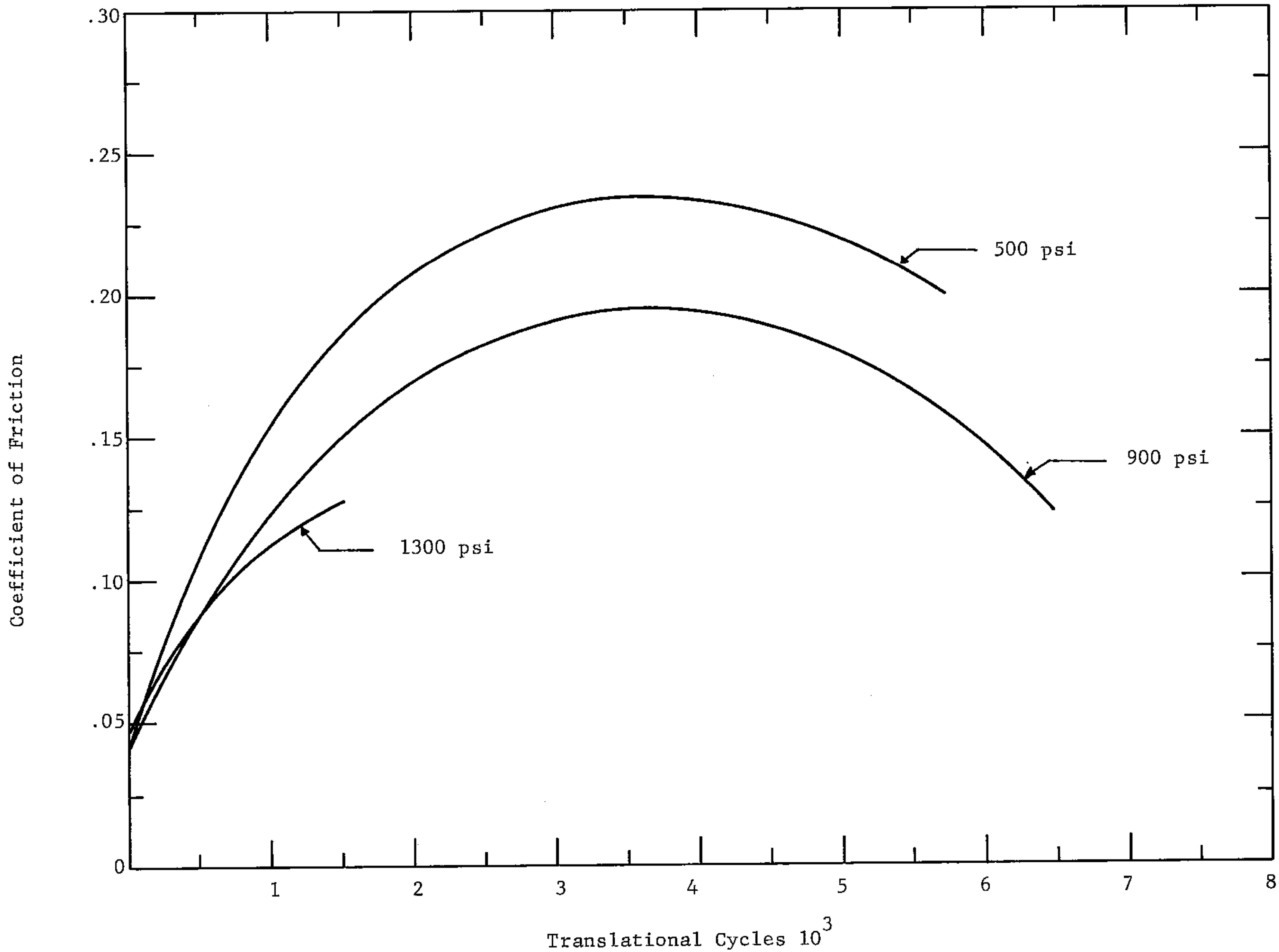


Figure 31. Translational test of specimen F7 under normal loads.

of the components without steel reinforcement indicated more wear near the edges resulting from high edge loads. The wear and load distributions were more uniform throughout the surface of the bearings utilizing the steel elements. When the load was removed, slight permanent deformations were also evident for the pad unreinforced with a steel sheet.

Additional laboratory work was undertaken to find a combination of TFE and rubber impregnated fabric materials which would not develop the delamination of the fabric backing observed with the previously tested specimens. The TFE filler content and the thickness of the fabric backing pad were considered possible factors influencing the performance of the bearing.

Specimens with 0, 15, and 25 percent glass-filled TFE surface elements were tested to determine the relationship of fatigue damage of the fabric pad and the frictional forces developed by the various fill compositions. Two samples with 15 percent filler sliding against a polished stainless steel surface resulted in partial delamination upon completing 7000 cycles of translational movement, which indicated that the rate of accumulative damage became less with a decrease in the coefficient of friction resulting from less filler. This relationship was further substantiated by tests of two unfilled specimens which showed no signs of deterioration after completing 7000 and 28000 cycles of testing. Figure 32 shows the friction coefficient for unfilled TFE with fabric backing (specimen F1) at load levels of 625 psi and 940 psi.

A decrease in accumulative damage was also indicated when testing pads of greater thicknesses incorporating the 25 percent glass-filled surface. Although signs of partial delamination were evident for the 3/4-inch specimen, damage had not progressed as rapidly as observed for the 1/2-inch samples previously tested. Testing of the 1 1/2-inch sample indicated no evidence of damage resulting from

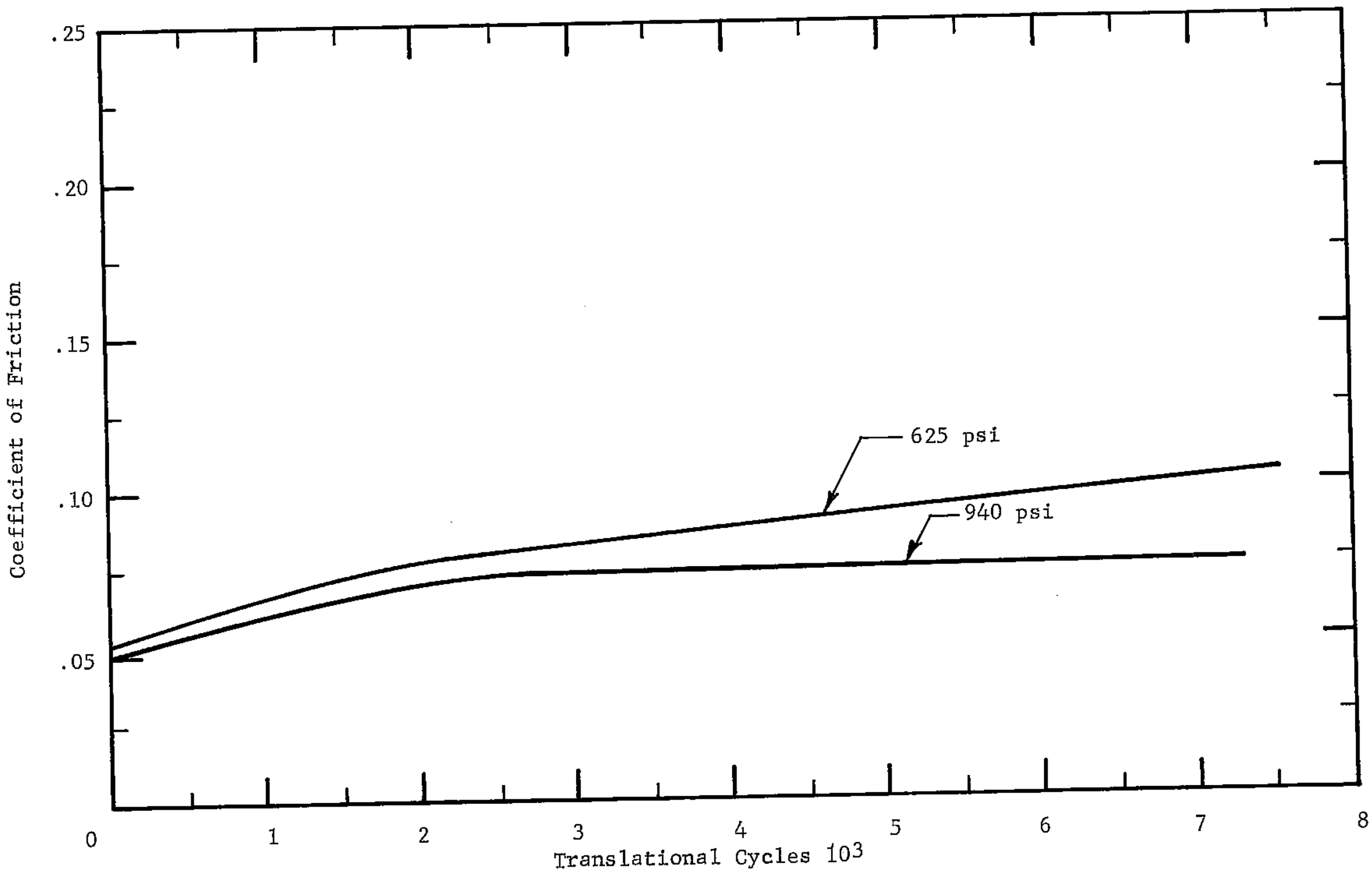


Figure 32. Translational Test of Specimen F1 Under Normal Loads

Figure 32. Translational test of specimen F1 under normal loads.

the tests.

Other TFE Test Bearings

In addition to the neoprene and fabric-backed bearings already discussed, other related types of TFE specimens were tested to include other types of bearing designs currently under consideration for use as bridge bearings. Two types of surfaces made of interwoven strands of TFE were tested as well as a high load capacity bearing using confined neoprene as a backing material. A list of these related bearings is as follows:

M1 - Surface layer of interwoven strands of bondable fibers and TFE fibers bonded to 10 gage stainless steel sheet bonded to 5- x 6- x 1/2-inch neoprene pad with 50 hardness.

M2 - Surface layer of loosely woven strands of pure TFE fibers mechanically bonded to 3- x 4- x 7/16-inch bronze plate with grid-embossed upper surface for bonding.

M3 - High load capacity rotation - translation bearing. Rotation is accommodated by a round neoprene pad sandwiched between two steel plates and laterally confined within a steel retaining ring. The top surface of the upper plate has a 3/32-inch-deep circular recess to accommodate a 1/8-inch-thick TFE pad which is 4 3/8 inches in diameter.

The opposing sliding surface for all of these specimens was a 12 gage polished stainless steel sheet.

The M1 bearing was first subjected to slip tests with normal loads increasing from 500 psi to 1500 psi in 250 psi increments. The decrease in friction coefficient with increasing load is illustrated in Figure 33. The bearing was then fatigue tested for 7700 cycles under a constant normal load of 500 psi (Figure 34). Near

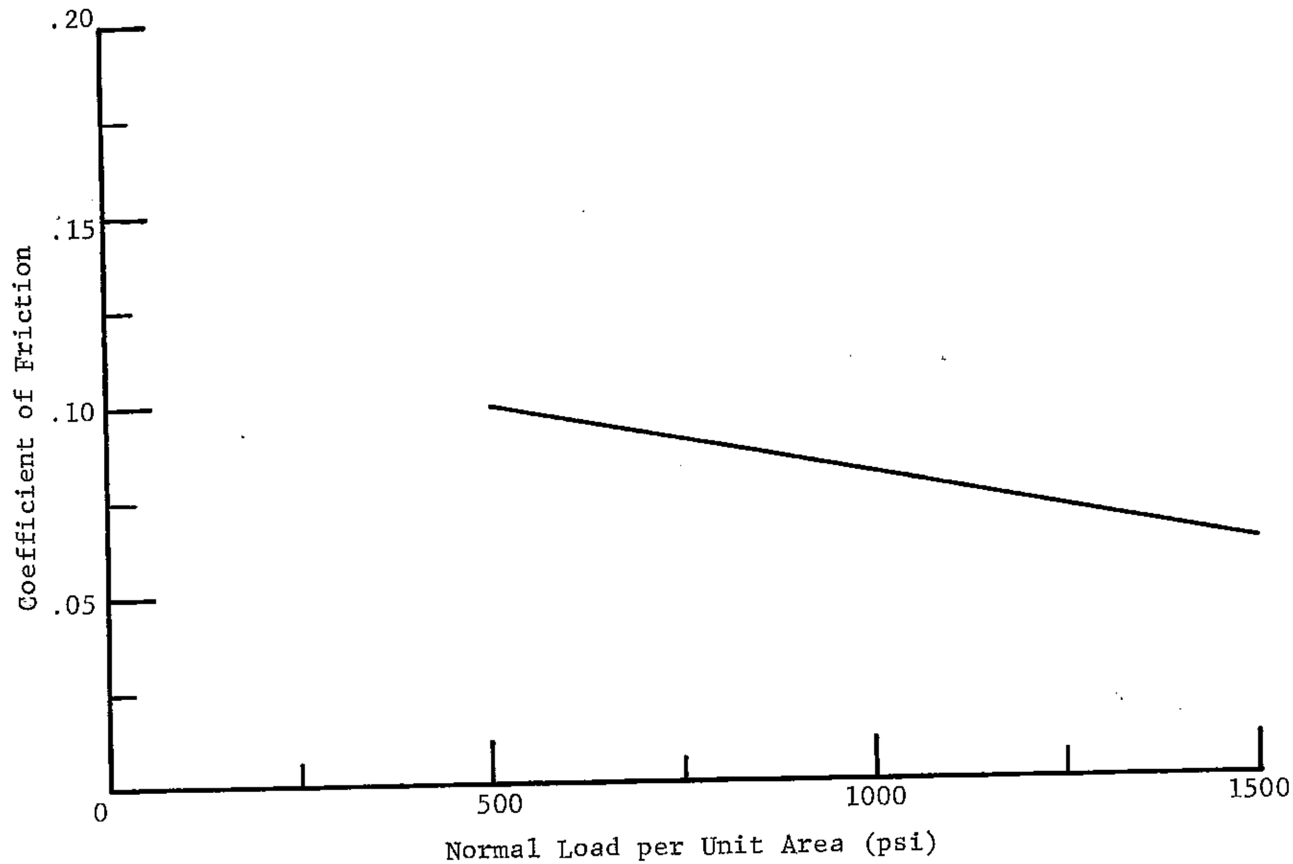


Figure 33. Coefficient of Friction vs. Vertical Pressure
for Specimen M1

Figure 33. Coefficient of friction vs. vertical pressure for specimen M1.

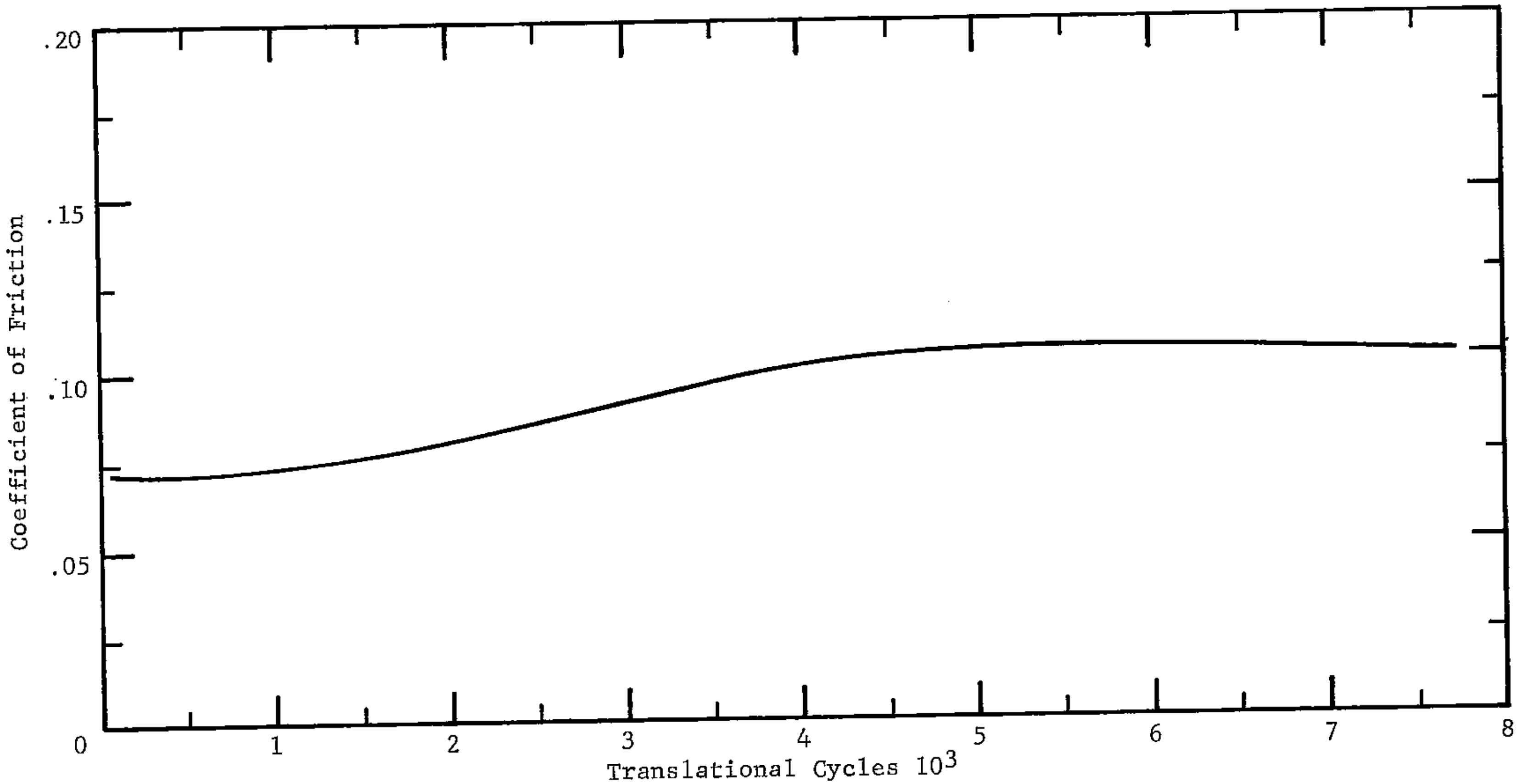


Figure 34. Translational Test of Specimen M1 Under Normal Load of 500 psi

Figure 34. Translational test of specimen M1 under normal load of 500 psi.

the end of the translational fatigue test the intermediate stainless steel layer had separated from the neoprene pad to the extent that only about 25 percent of the bonded area was still intact. The use of a harder rubber backing and a stronger bonding agent would add greatly to the durability of this bearing.

The M2 specimen was also tested under varying and constant normal loads. Since the bronze-backed bearing is capable of supporting heavier loads, the normal loads were increased during the slip test from 500 psi to 3500 psi in increments of 500 psi (Figure 35). The bearing was then fatigue tested for 9700 cycles at a constant normal load of 2000 psi (Figure 36). Little change in the friction coefficient occurred during the translational fatigue test.

The M3 specimen was the most impressive of all bearings tested. Throughout two cyclic tests conducted at load levels of 2000 psi and 3000 psi, the coefficient of friction remained very low and stayed nearly constant throughout both tests (Figures 37 and 38). This bearing is considered to be an excellent expansion type bearing under heavy loading conditions which require provisions for rotation.

Effect of Contamination

Thus far the testing program consisted of tests under constant or increasing loads on samples with clean TFE surfaces. One source of possible damage to the bearings under field conditions is the contamination of the TFE surfaces with dirt and grit. An alleged advantage of the TFE bearings over their metal counterparts is the ability of the TFE layers to absorb particles of grit by embedment within the surface. This property would prevent large sustained increases in the coefficient of friction. Upon completion of the typical cyclic tests, certain bearing surfaces were contaminated with sand particles, and limited additional tests were made to investigate the ability of the TFE layers to absorb the contamination.

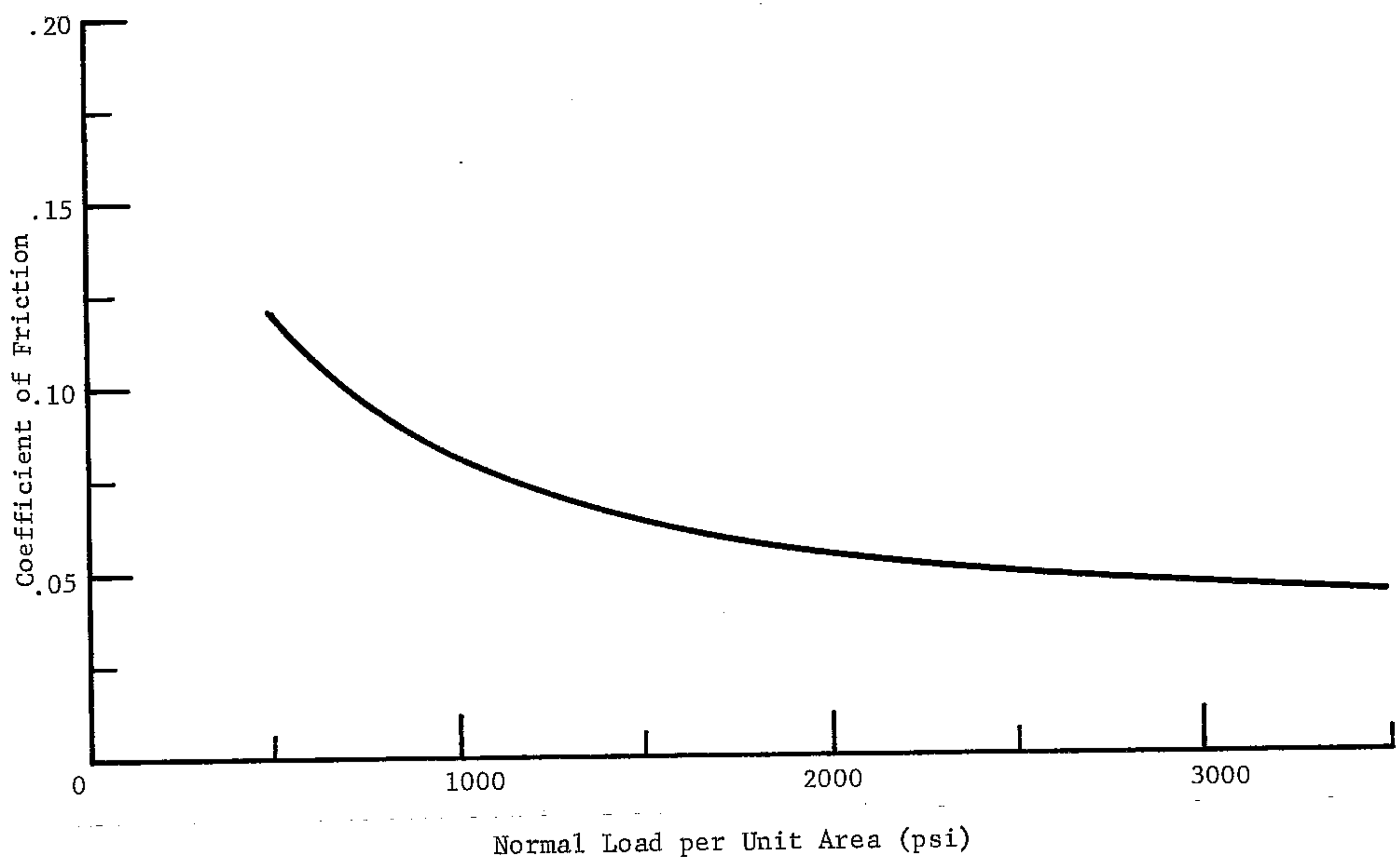


Figure 35. Coefficient of friction vs. vertical pressure for specimen M2.

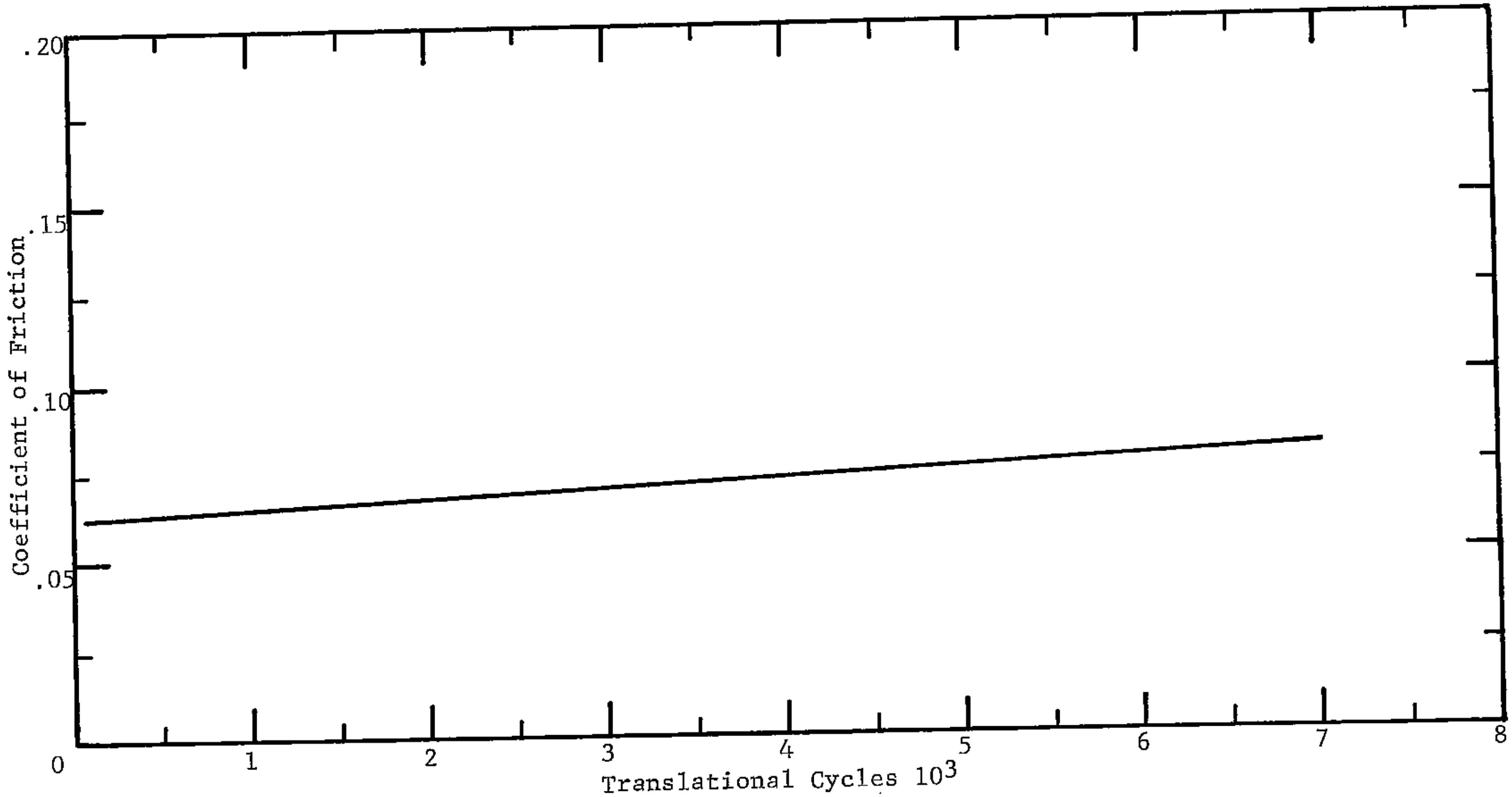


Figure 36. Translational Test of Specimen M2 Under Normal Load of 2000 psi.

Figure 36. Translational test of specimen M2 under normal load of 2000 psi.

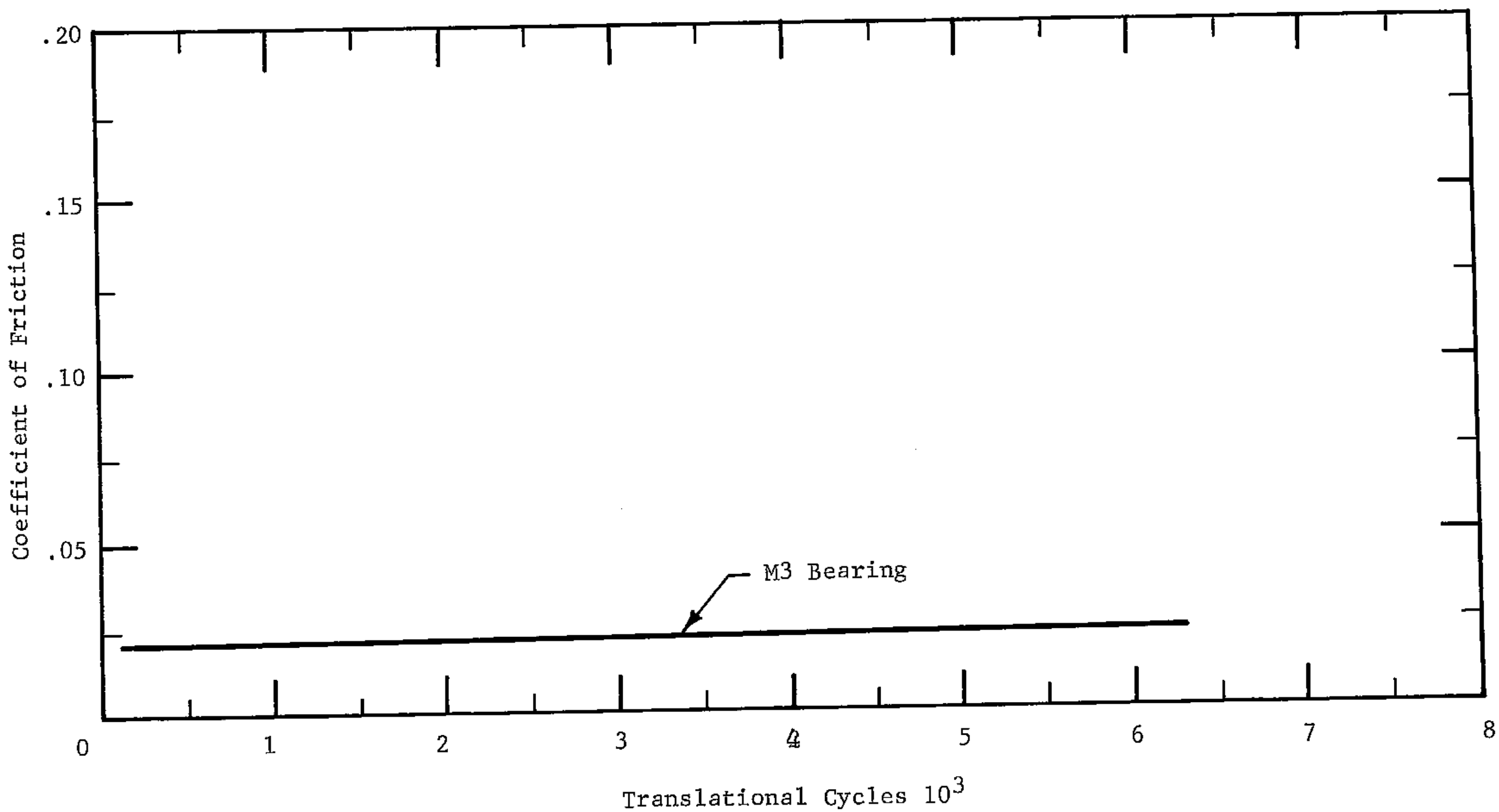


Figure 37. Translational test of specimen M3 under normal load of 2000 psi.

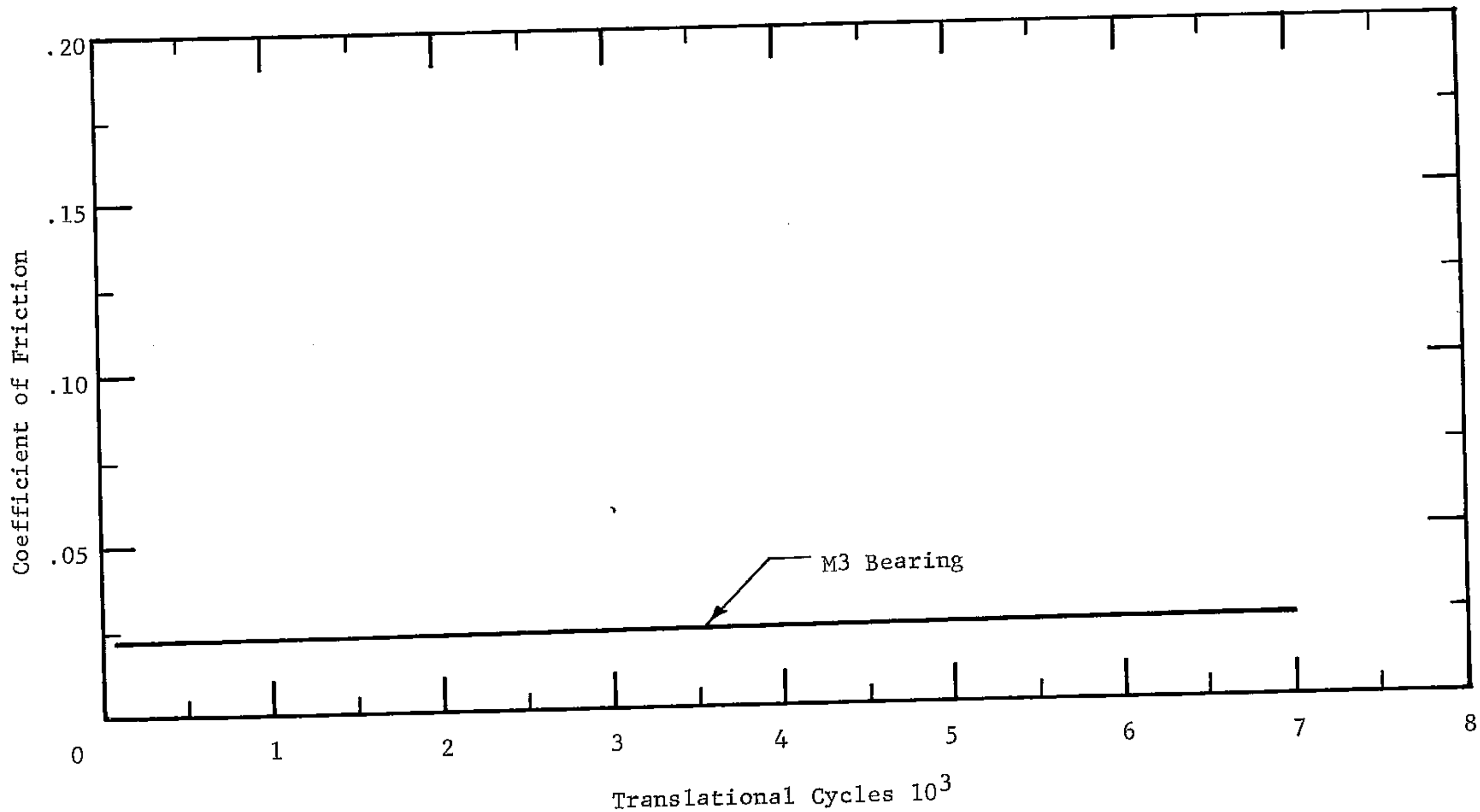


Figure 38. Translational test of specimen M3 under normal load of 3000 psi.

A pure TFE sample (F1) with an initial friction coefficient of 0.05 and a final coefficient of 0.06 after 7300 test cycles at a vertical load of 940 psi was contaminated with sand particles and subjected to 6700 additional cycles at a load of 625 psi. At the beginning of the contamination test a coefficient of friction of 0.27 was recorded which diminished to 0.14 after 6700 cycles.

Another unfilled sample (F2) which maintained a friction coefficient of 0.08 throughout 7700 cycles at a load of 600 psi was contaminated with sand particles and retested at 600 psi. After 1770 cycles the TFE surface layer had completely separated from the fabric backing and the test was halted. The friction coefficient decreased slightly from 0.29 to 0.21 during the test.

A contamination test was also conducted on a 25 percent glass-filled specimen (A14) backed by adiprene. The friction coefficient decreased from 0.20 to 0.16 after 7400 cycles. This compares to a constant value of 0.09 for the coefficient of friction throughout 7600 cycles of testing before contamination. After testing under contaminated conditions, the surface of this sample was severely striated.

Interwoven strands of TFE fibers have been proposed as a bearing surface which is more effective in absorbing contaminating grit particles. This absorbing characteristic is based on the premise that any dirt particles will work their way between the loosely woven fibers and become embedded beneath the surface of the material and, therefore, have less effect on the coefficient of friction of the surface.

In order to study the ability of the interwoven TFE surface to absorb contamination, the M2 bearing was contaminated with sand particles and tested for 7000 cycles at a constant normal load of 2000 psi (Figure 39). The coefficient of friction decreased rapidly early in the test and after 1200 cycles remained nearly equal to the coefficient of friction of the uncontaminated specimen. The

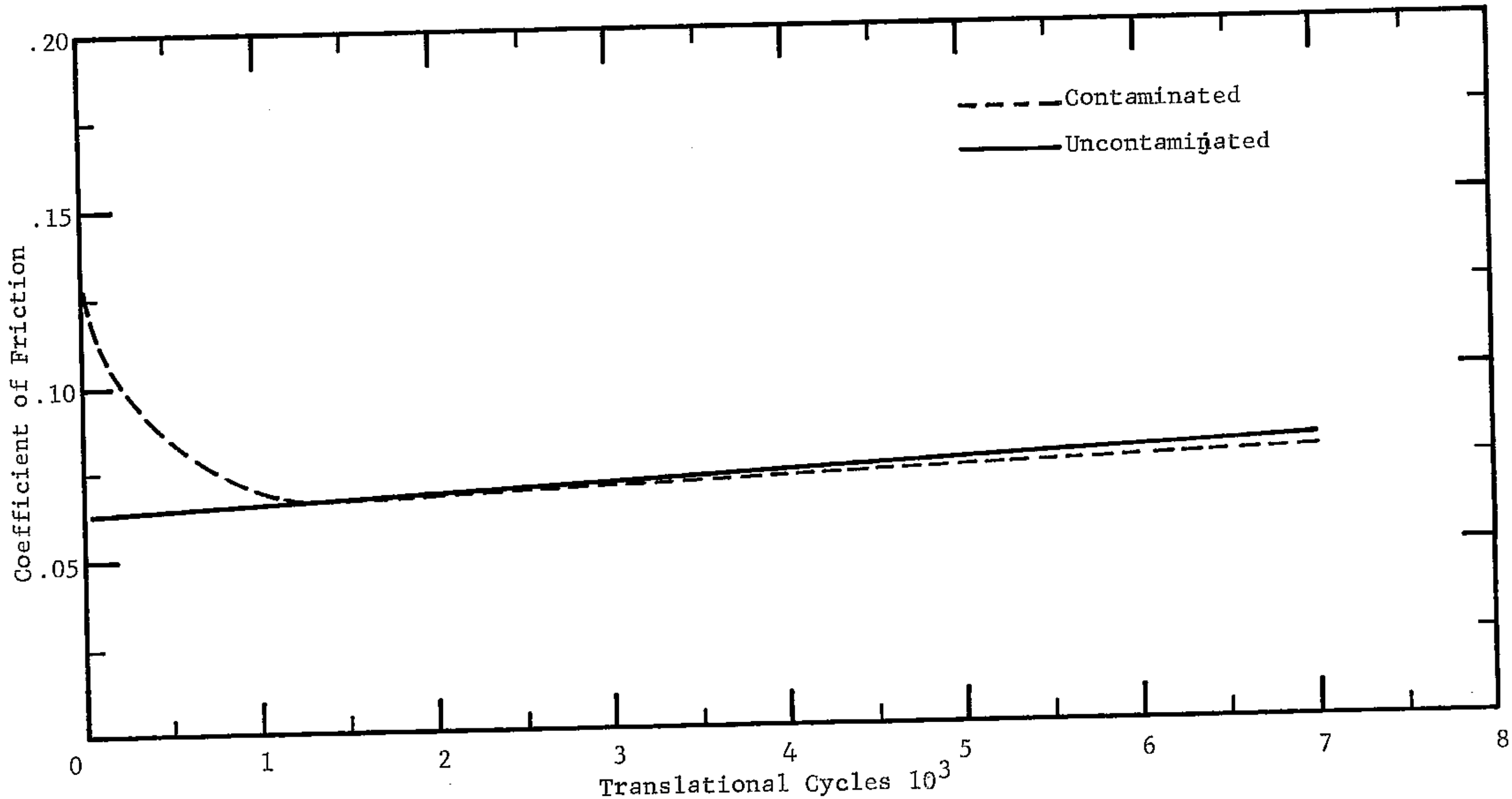


Figure 39. Comparison of Contaminated and Uncontaminated Translational Tests for M2 Specimen Under Normal Load of 2000 psi.

Figure 39. Comparison of contaminated and uncontaminated translational test for M2 specimen under normal load of 2000 psi.

interwoven fibers appear to absorb grit particles better than any solid TFE surface tested.

Bronze Bearings

Translational fatigue laboratory tests were also conducted on graphite-impregnated, self-lubricating bronze bearings. Since this type of bearing is currently used for expansion bearings at the abutments of concrete bridges, the tests on this bearing were made for comparison with similar tests on the experimental TFE bearings.

As indicated in Figure 40, cyclic tests of the bronze bearing conducted at various load levels indicated a degree of inconsistency since the highest and lowest test loads yielded intermediate values for the friction coefficient. The reason for this inconsistency is unknown. At all test load levels the coefficient of friction increased to a maximum value after a few thousand cycles and then tapered off to a reduced value at 7000 cycles.

The coefficient of friction of the bronze bearing compares favorably with that of the fabric-backed 25 percent glass-filled specimens. However, the unfilled fabric-backed samples and the neoprene-backed filled bearings recorded a lower and more consistent friction coefficient at all load levels. From the results of the laboratory and field tests, it appears that several TFE bearing configurations offer less resistance to sliding than the graphite impregnated bronze counterparts.

Although laboratory tests indicate that the performance of the bronze bearings may be equivalent to certain filled TFE specimens, it should be noted that the laboratory tests involved movements greatly accelerated above those encountered in field applications. For slow movements such as those that occur at a bridge structure, the bronze bearings lack the antistick characteristics inherent in the

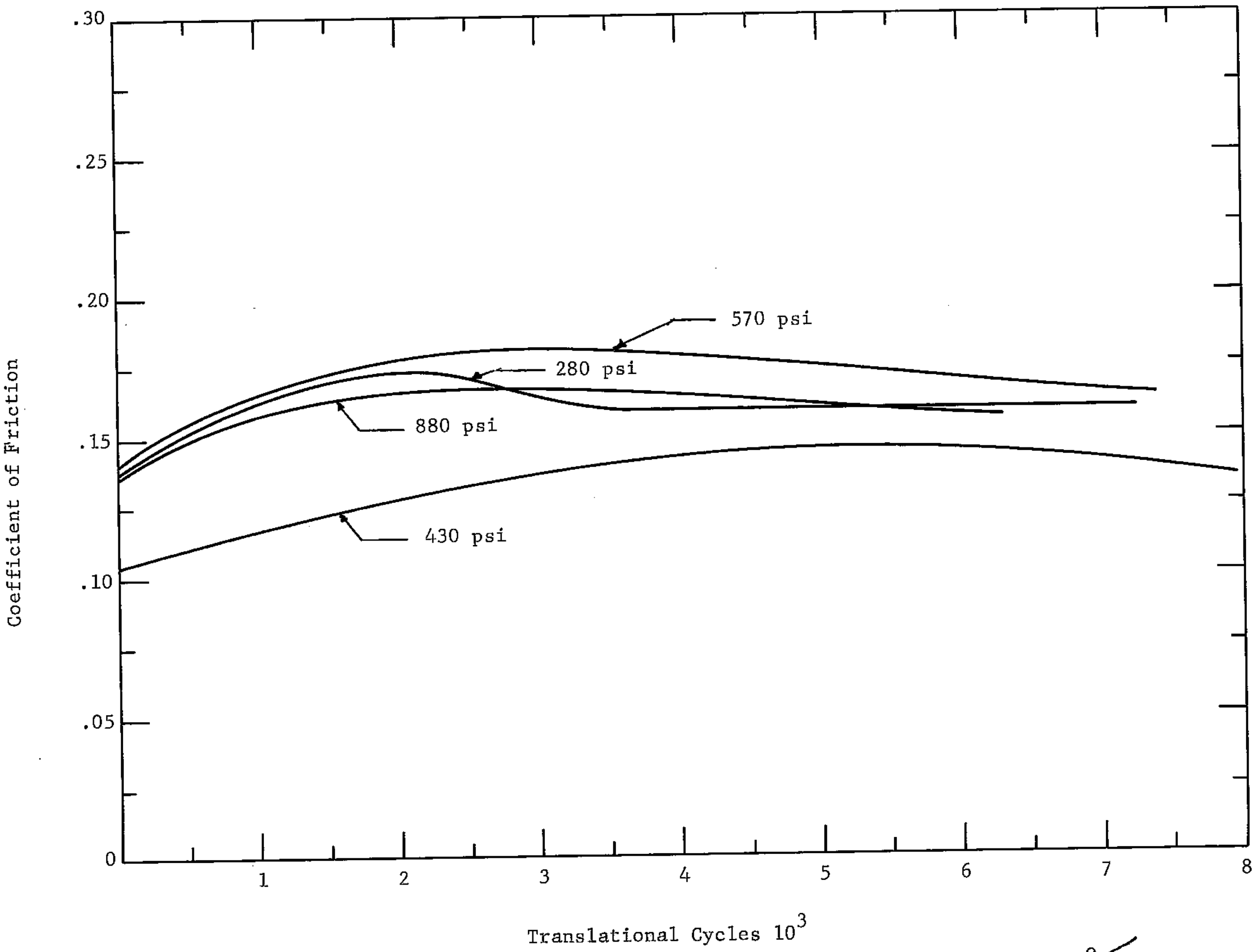


Figure 40. Translational Tests of Bronze Specimens Under Normal Loads

Figure 40. Translational test of bronze specimens under normal loads.

TFE material and, after prolonged use the bronze bearings tend to freeze. As indicated in the field test results, nearly twice as much daily movement occurred at the TFE bearings as occurred at the bronze bearings.

CONCLUSIONS AND RECOMMENDATIONS

The results of this study indicate that the performance of the TFE bearings is better than the graphite impregnated bronze bearings currently used for abutment expansion bearings on concrete bridges. The field tests show that, for the same expansion length of a prestressed concrete I-beam structure, twice as much daily movement occurred at the TFE bearings as at the bronze bearings. The tendency for the bronze bearings to bind up or freeze and not to allow free expansion of the structure is verified by the data collected during the field tests. The theoretical expansion that would have taken place if the structure were completely free to expand can not be accurately correlated with the actual movement of the structure due to the lack of temperature data over the depth of the superstructure. The TFE bearings, however, with the qualities of antistick surfaces and low coefficients of friction, appear to be a significant improvement over previous bearing designs.

Many combinations of TFE surfaces and backing materials are commercially available, and the selection of the optimum bearing for a specific application is complicated by this variety of products. The bearings tested during the research consisted of samples obtained from several manufacturers. The test results illustrate the differences in the performance of specimens obtained from the several manufacturers as well as differences in the performance of specimens obtained from the same manufacturer.

The bearing surfaces laboratory tested in the research include unfilled TFE layers, filled TFE layers containing 15 and 25 percent glass fiber filler, and the graphite impregnated bronze surface. The performance of the bronze bearing compared well with the glass-filled TFE surfaces, however, the coefficient of friction of the bronze samples was higher and less consistent than the unfilled specimens.

Because a comparison of the TFE surfaces shows that the unfilled TFE performed better than the filled specimens, it is the recommendation of this report that the unfilled TFE be used for bridge bearings. Although the glass fiber reinforcement improves the resistance of TFE bearings to wear and creep effects, the magnitude of the loads and the rate of movement of a bridge structure are not believed to be severe enough to cause a critical amount of wear and creep. Further study of the creep effects will be made, however, to support the contention that the unfilled TFE will perform adequately as a bridge bearing.

The parameters of rubber hardness, degree of slope, and shape factor were investigated for the rubber-backed specimens. Neoprene backing with 50, 60, and 70 hardness and adiprene backing with 80 hardness were evaluated. During the tests the softer specimens were observed to deform appreciably more than the harder samples with lipping of the rubber at the exposed edges increasing with decreasing hardness. This distortion appeared to have little effect on the performance of the bearings, although the backing did separate slightly from the stainless steel interlayer. Because less strain occurs in the harder rubber under horizontal loads, it is concluded that 70 or more hardness rubber is more suitable for bridge bearing application.

Slopes greater than 2 1/2 percent between nonparallel load surfaces appear excessive for the 1/2-inch elastomeric pad. A limiting value of 1 1/2 percent is recommended as the maximum slope permitted for the change in grade of a beam between bearing seats. This limitation will provide some factor of safety for construction contingencies such as unevenness of the bearing seat and camber of the prestressed member.

Shape factor was also considered as a parameter which could influence the performance of the rubber backing material. The tests indicate, however, that the difference in behavior of rubber-backed specimens with shape factors of 2.7 and 5.4 is negligible. Consequently, no recommendation is made concerning the shape factor of the bearing backing material.

Laboratory tests on the 1/2-inch-thick fabric-backed specimens with 25 percent glass-filled surface layers had to be halted before completion of 7000 translation cycles because of delamination of the fabric material. Signs of initial damage appeared at about 2000 to 3000 cycles, and in several cases the specimen was completely delaminated before 4500 cycles. Two samples with 15 percent glass filler completed 7000 test cycles with only partial delamination occurring. In addition, two unfilled specimens completed 7000 and 28000 test cycles with no sign of delamination. From the laboratory test results it is concluded that the fabric material is suitable for backing bridge bearings when using unfilled TFE as the sliding element. The performance of the fabric backing with a filled TFE surface was substantially improved by increasing the thickness of the fabric material. Fatigue testing of a specimen backed with a 1 1/2-inch fabric pad indicated no evidence of damage after completing 7000 cycles.

The fabric-backed bearings with 25 percent glass filler performed well during the field test, which lasted three years and four months. No visible signs of damage were apparent in either fabric specimen. However, since the laboratory tests indicated delamination of the 25 percent glass-filled fabric specimen, one fabric-backed bearing was left in place for further observation after the other

TFE specimens were removed and replaced.

In addition to specimens with a surface of solid TFE, other samples with surfaces of woven TFE fibers were tested. One sample with interwoven strands of bondable fibers and TFE fibers backed by stainless steel bonded to 50 hardness neoprene suffered 75 percent separation of the neoprene from the stainless steel after 7700 cycles at 500 psi. The use of a harder rubber backing and a stronger bonding material would greatly improve the performance of this bearing.

Another sample with a surface of loosely interwoven pure TFE fibers backed by an embossed bronze plate performed well under a constant load of 2000 psi for 9700 cycles. Under contaminated conditions this bearing performed better than any other specimen. The coefficient of friction after contamination quickly approached the friction coefficient recorded during the uncontaminated test.

As a matter of interest, one sample was tested which is particularly suitable for applications requiring high load capacity. This specimen consists of a round neoprene pad confined by a steel ring and a sliding surface of pure TFE. Throughout two cyclic tests conducted at load levels of 2000 psi and 3000 psi, the coefficient of friction consistently remained at about 0.02. Although the bearing is more expensive than other bearings suitable for application to highway bridges, it can be considered as an alternate design when a high load capacity is required.

From the results of this research, it appears that the most economical and durable bearing design for use at the abutments of prestressed concrete bridges should have a sliding surface of pure unfilled TFE. The backing material should consist of either 70 hardness rubber or rubber impregnated fabric with an intermediate steel plate bonded between the TFE surface layer and the backing material. The opposing sliding surface may be either stainless steel or TFE bonded directly to a steel fill plate. Although other TFE bearing designs may provide adequate performance, for optimum durability and economy the suggested prototype is recommended.

A P P E N D I X

APPENDIX A

TABLE 1.

RUBBER-BACKED TFE EXPERIMENTAL BEARING ASSEMBLIES

Type Sample	No. of Samples	TFE Thickness (in.)	% Glass Filler	Backing	Backing Thickness (gage-in.)	Hardness	Shape Factor	Opposing Sliding Surface	Thickness of Opposing Surface (in.-gage)
N1	3	1/16	25	SS-N	16G-1/2	50	2.7	SS	16G
N2	3	1/16	25	SS-N	16G-1/2	50	2.7	TFE-SS-N	1/16-16G-1/2
N3	3	1/16	25	N	1/2	50	2.7	TFE-SS-N	1/16-16G-1/2
N4	1	3/32	25	SS-N	10G-1/2	60	2.7	TFE-SS	3/32-10G
N5	1	3/32	25	SS-N	10G-1/2	70	2.7	TFE-SS	3/32-10G
N6	1	3/32	25	SS-N-SS	10G-1/2-10G	50	2.7	TFE-SS	3/32-10G
N7	1	3/32	25	SS-N-SS	10G-1/2-10G	70	2.7	TFE-SS	3/32-10G
N8	1	3/32	25	SS-N	10G-1/4	50	5/4	TFE-SS	3/32-10G
N9	1	3/32	25	SS-N	10G-1/4	70	5/4	TFE-SS	3/32-10G
N10	1	3/32	25	SS-N-SS	10G-1/4-10G	50	5.4	TFE-SS	3/32-10G
N11	1	3/32	25	SS-N-SS	10G-1/4-10G	70	5.4	TFE-SS	3/32-10G
N12	1	3/32	25	SS-N-SS-N	10G-1/4-10G-1/4	50	5.4	TFE-SS	3/32-10G
N13	1	3/32	25	SS-N-SS-N	10G-1/4-10G-1/4	70	5.4	SS	10G
A14	2	3/32	25	SS-A	10G-1/2	80	2.7	TFE-SS	3/32-10G
A15	1	3/32	25	SS-A	10G-1/4	80	5.4	TFE-SS	3/32-10G

TFE - Tetrafluoroethylene (Teflon)
SS - Stainless Steel

N - Neoprene
A - Adiprene

TABLE 2.

FABRIC-BACKED TFE EXPERIMENTAL BEARING ASSEMBLIES

Type Sample	No. of Samples	TFE Thickness (in.)	% Glass Filler	Backing	Backing Thickness (gage-in.)	Opposing Sliding Surface	Thickness of Opposing Surface (gage)
F1	3	1/32	0	F	1/2	SS	20G
F2	1	1/32	0	F	1	SS	20G
F3	2	1/32	15	F	1/2	SS	20G
F4	3	1/16	25	F	1/2	SS	16G
F5	1	3/32	25	F	3/4	SS	20G
F6	1	3/32	25	F	1 1/2	SS	20G
F7	3	1/16	25	SS-F	16G- 1/2	SS	16G

SS - Stainless Steel
F - Fabric

APPENDIX B

TENTATIVE SPECIFICATIONS FOR TFE EXPANSION BEARINGS

General

TFE fluorocarbon resin expansion bearings shall be furnished and installed in accordance with the plans and specifications and shall conform to the lines, dimensions, design, and material composition as shown on the plans and as specified herein. The work shall consist of the fabrication or manufacture, packaging and handling, and installation of the bearings. The work shall also include furnishing the structural steel bearing plates and the stainless steel sheets for sliding surfaces and bonding of the sheets to the structural steel plates as shown on the plans.

The TFE bearings shall be composed of pure unreinforced tetrafluoroethylene fluorocarbon resin sheets bonded in the specified combination with elastomeric or fabric pads and stainless steel sheets as shown on the plans. All material used in the manufacture of the bearings shall be new and unused with no reclaimed material incorporated into a finished bearing. The dimensions of the finished bearings shall be within plus or minus 1/16 inch of the plan dimensions. Unless otherwise approved by the engineer, the bearing assemblies shall be furnished as a complete unit from one manufacturing source.

TFE Material

The TFE resin shall be 100 percent virgin material meeting the requirements of ASTM Designation D 1457-69. The TFE sheet shall consist of pure TFE resin, molded by pressure and heat, and skived into sheets of 1/16-inch thickness. The finished TFE sheet shall conform to the following mechanical and physical properties.

ASTM Standard	Physical Properties	
D 1457	Tensile strength (psi)	2800 min.
D 1457	Tensile elongation (%)	200 min.
D 621	Deformation under 2000 psi load at 78° F (%)	15 max.
D 1706-61	Hardness (Shore D) at 78° F	50-65
D 1457	Specific gravity	2.14 ± 0.03
	Melting point (F)	623 ± 2°

Elastomeric Pad

The elastomeric material shall be 100 percent virgin chloroprene determined from a test specimen conforming to Part B of ASTM Designation D 15 meeting the following requirements.

ASTM Standard	Physical Properties	
D 2240	Hardness (Shore A)	70 ± 5
D 412	Tensile strength, min. psi	2500
	Ultimate elongation, min. %	300
	Heat Resistance	
D 573	Change in durometer hardness, max. points	+15
70 hr.	Change in tensile strength, max. %	-15
@ 212° F	Change in ultimate elongation, max. %	-40
	Compressive Set	
D 395	22 hrs. @ 212° F, max. %	35
	Ozone	
D 1149	100 ppm ozone in air by volume 20% strain 100 ± 2° F, 100 hrs. mounting procedure D 518, Procedure A	No cracks
	Adhesion	
D 429,B	Bond made during vulcanization, lbs. per inch	40

The elastomeric pads shall conform to the requirement of the class designated as RMA-A3-F3-T.063-B_2, Grade 2, Method B, in the Rubber Handbook, Second Edition, 1963, published by the Rubber Manufacturers Association, Incorporated.

Preformed Fabric Pad

The fabric bearing pads shall be manufactured of all new (unused) materials and composed of multiple layers of prestressed cotton duck, 8 ounces per net square yard, duck warp count 50 $\pm$ 1 threads per inch and filling count 40 $\pm$ 2 threads per inch, 2 yarns per thread, 64 plies per inch of finished pad thickness, impregnated and bound with a high quality rubber compound containing rot and mildew inhibitors, and antioxidants into resilient pads of uniform thickness. The pads shall withstand compressive loads perpendicular to the plane of laminations of not less than 10,000 psi before breakdown. Load deflection properties in accordance with procedures of MIL-C-882 shall be the following maximum percentages of total pad thickness: 10 percent at 1000 psi and 15 percent at 2000 psi. When loaded to 2000 psi, permanent set, as load is removed in accordance with procedures of MIL-C-882, shall be a maximum of 5.0 percent of the original "zero point" thickness. Shore Durometer shall be 90 $\pm$ 5. The ratio of lateral expansion to vertical deflection shall not exceed 0.25 when loaded to 1500 psi. Thickness shall be as shown on drawings within tolerances of $\pm$ 5 percent. No visual evidence of damage or deteriorations by environmental effects of sunshine, humidity, salt spray, fungus, and dust shall be present when tested in accordance with MIL-E-5272.

Stainless Steel Sheets

Stainless steel sheets shall be of the gage specified on the plans and shall conform to ASTM A240, Type 304. The sliding surface of the top stainless steel sheet shall have a Type 4 finish.

Structural Steel Bearing Plates

The structural steel bearing (top) plates shall be furnished in accordance with Section 507 of the Standard Specifications for Road and Bridge Construction, adopted January 2, 1971. Exposed surfaces of the plates shall be shop painted in accordance with Sections 509.03 and 509.04.

Bonding Adhesive

The adhesive material for bonding the elastomeric or fabric pad and the TFE sheet to the interior stainless steel sheet, the stainless steel sheet for a sliding surface to the top structural steel bearing plate, and the elastomeric or fabric pad to the concrete bearing seat shall be epoxy resin of the two-component, medium viscosity, high temperature type conforming to the requirements of the Federal Specification MMM-A.134. The bonding agent shall be applied on the full area of the contact surfaces.

Certification

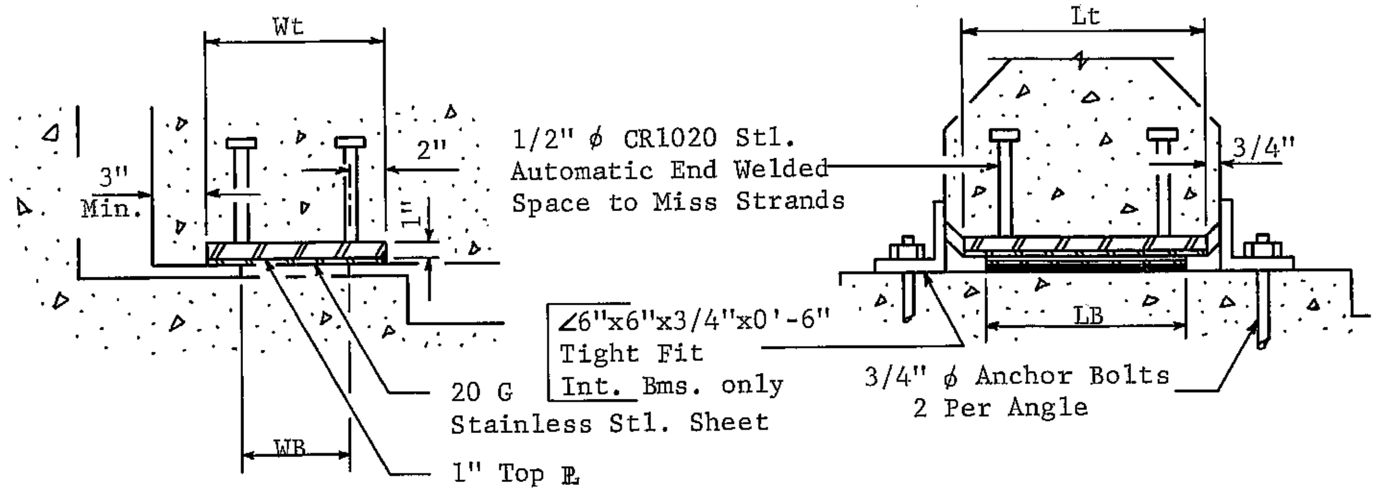
The contractor shall furnish to the engineer a written certification by the bearing manufacturer that the bearings furnished conform to all of the requirements shown on the plans and stipulated herein.

Packaging

The bearings shall be packaged and protected in such a manner that they will not be damaged and the contact surfaces of the sliding elements will not be contaminated while being handled, transported, or stored. Any bearing damaged by handling, transporting, or storing shall be replaced by the contractor at his expense.

Basis of Payment

The cost of furnishing and installing the bearing assemblies specified herein shall be incidental to the contract, and no additional compensation will be allowed.



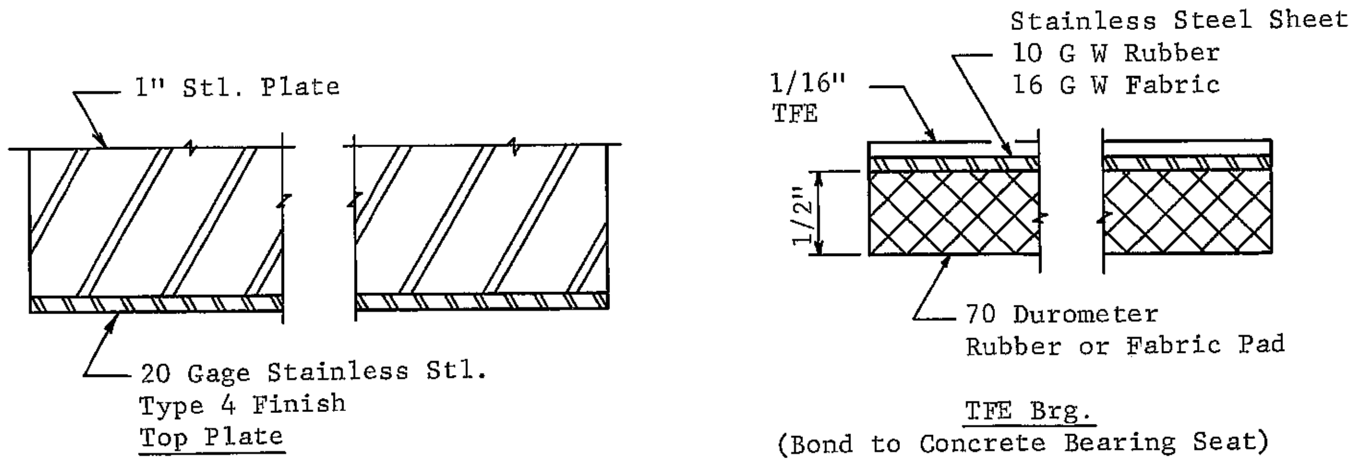
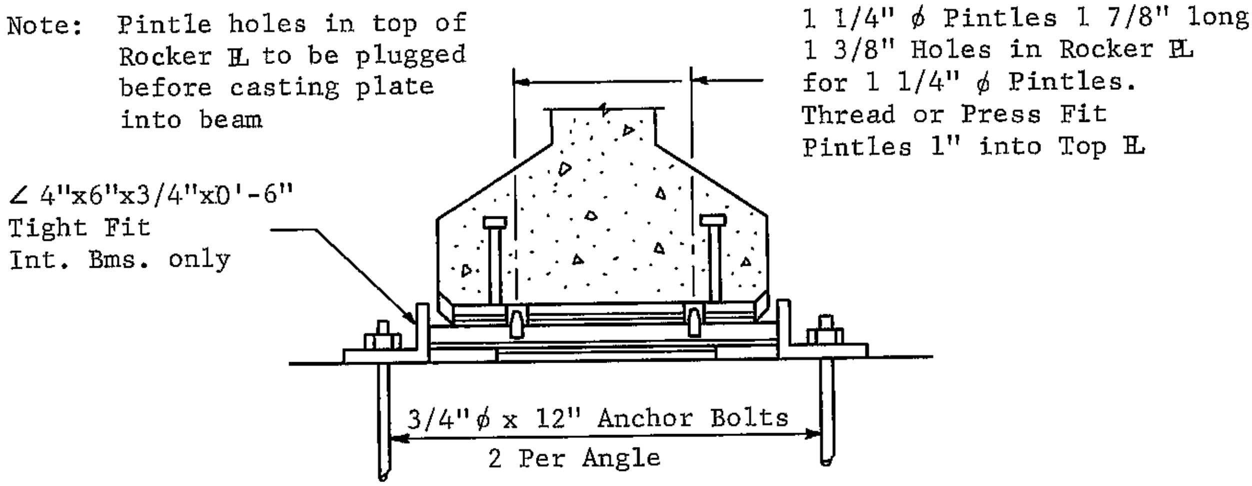


Table of Dimensions and Allowable Loads

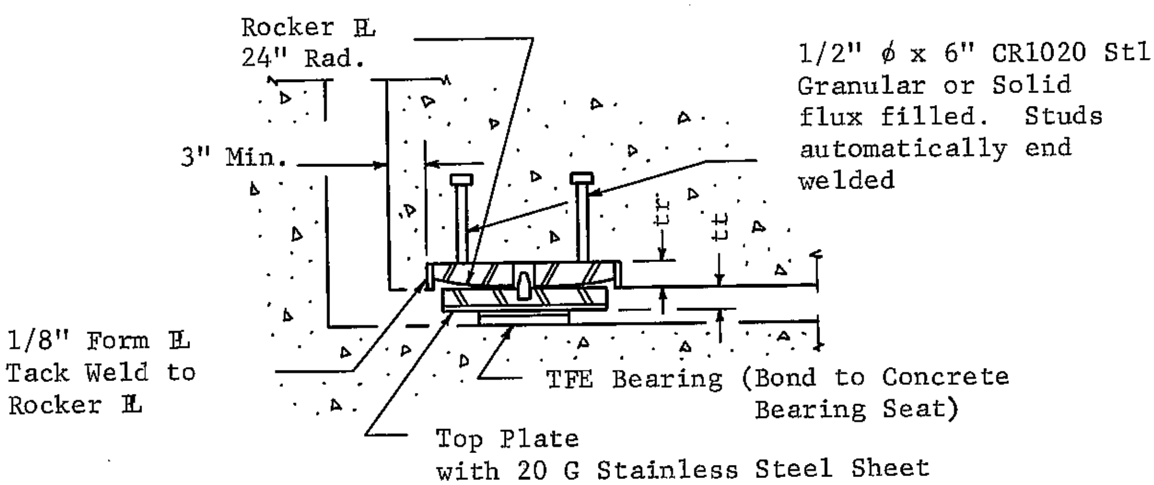
Beam	Lt	Wt	Lb	Wb	Max. DL	Max. DL+LL	Min. DL
36"	16 1/2"	12"	14"	7"	49.0^k	78.4^k	19.6^k
	16 1/2"	11"	14"	6"	42.0^k	67.2^k	16.8^k
	16 1/2"	10"	14"	5"	35.0^k	56.0^k	14.0^k
	16 1/2"	10"	12"	5"	30.0^k	48.0^k	12.0^k
42" & 48"	20 1/2"	12"	18"	7"	63.0^k	100.8^k	25.2^k
	20 1/2"	11"	18"	6"	54.0^k	86.4^k	21.6^k
	20 1/2"	10"	18"	5"	45.0^k	72.0^k	18.0^k
	20 1/2"	10"	14"	5"	35.0^k	56.0^k	14.0^k

Note: Allowable loads based on 200 psi Min. DL, 500 psi Max. DL, and 800 psi Max. (DL + LL)

Figure 1. Tentative design details for TFE bearings - 1 1/2 percent slope limitation.



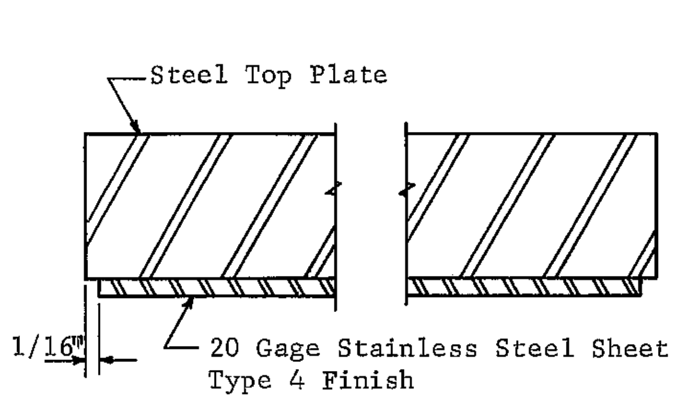
TFE Sliding Bearing



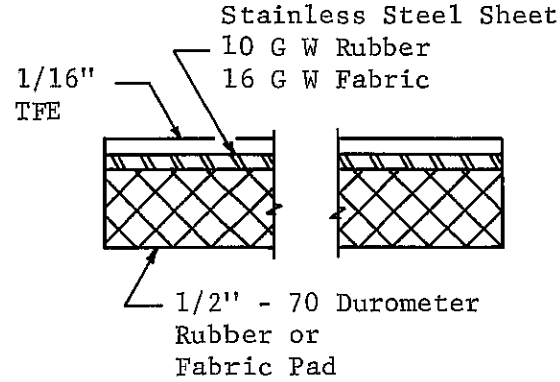
Cross Section
(Note: See Figure III for additional details)

Figure 2. Tentative design details for TFE bearings - no slope limitation.

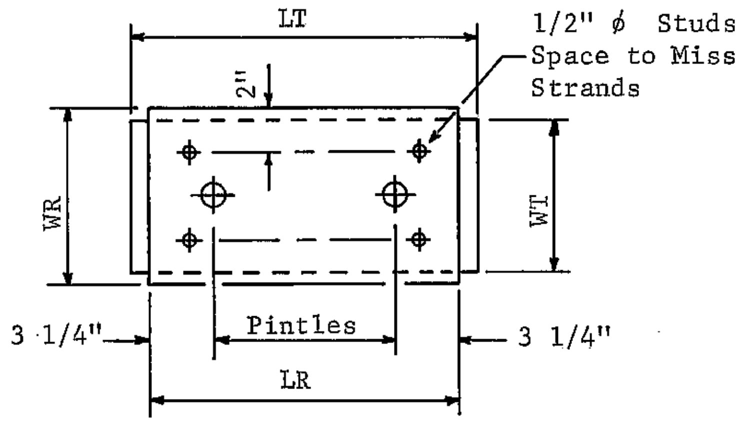
Figure 2. Tentative design details for TFE bearings - no slope limitation.



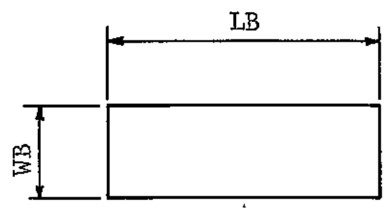
Top Plate



TFE Bearing



Top Assembly



Plan
TFE Brg.

Table of Dimensions and Allowable Loads

Bm	tr	tt	LR	WR	LT	WT	LB	WB	Max. DL	Max. DL+LL	Min. DL
36"	1 1/2"	1 1/8"	16 1/2"	13"	18 1/2"	12"	14"	7"	49.0^k	78.4^k	19.6^k
	1 3/8"	1"	16 1/2"	12"	18 1/2"	11"	14"	6"	42.0^k	67.2^k	16.8^k
	1 1/4"	1"	16 1/2"	11"	18 1/2"	10"	14"	5"	35.0^k	56.0^k	14.0^k
	1 1/8"	1"	16 1/2"	11"	18 1/2"	10"	12"	5"	30.0^k	48.0^k	12.0^k
42" & 48"	1 5/8"	1 1/8"	20 1/2"	13"	22 1/2"	12"	18"	7"	63.0^k	100.8^k	25.2^k
	1 1/2"	1"	20 1/2"	12"	22 1/2"	11"	18"	6"	54.0^k	86.4^k	21.6^k
	1 1/4	1"	20 1/2"	11"	22 1/2"	10"	18"	5"	45.0^k	72.0^k	18.0^k
	1 1/8"	1"	20 1/2"	11"	22 1/2"	10"	14"	5"	35.0^k	56.0^k	14.0^k

Note: Allowable loads based on 200 psi Min. DL, 500 psi Max. DL and 800 psi Max. (DL+LL)

Figure 3. Tentative design details for TFE bearings - no slope limitation.